University of Texas Mission Design Presents

Gateway

An Earth orbiting transportation node

Design Review 2

The University of Texas at Austin
Woolrich Hall Room 209
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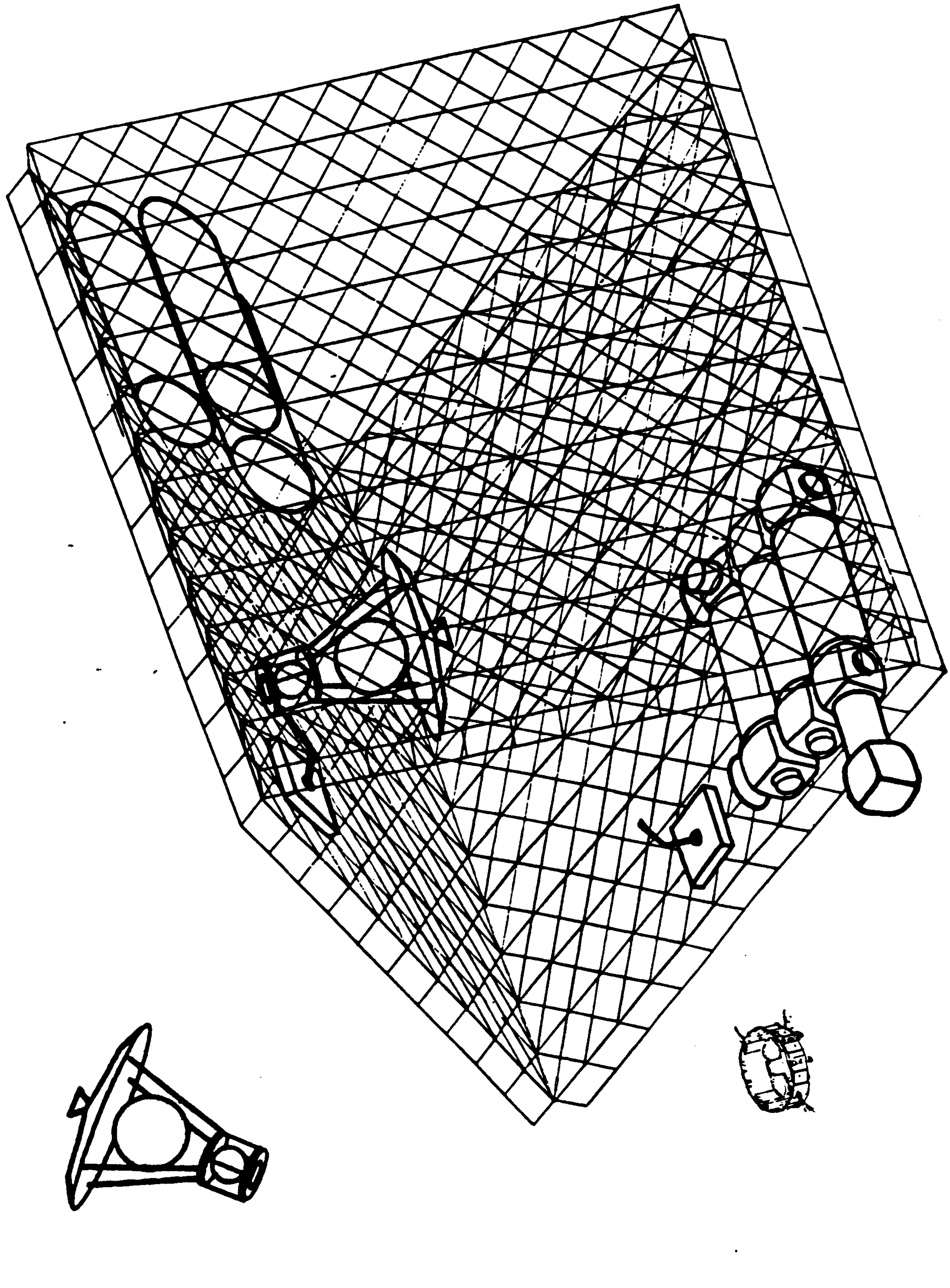

ABSTRACT

Gateway
A Design for an Earth Orbiting Transportation Hub
Dedicated to Supporting the Lunar Base

University of Texas Mission Design (UTMD) has outlined the components that a space-based transportation facility must include in order to support the first decade of Lunar base buildup. After studying anticipated traffic flow to and from the hub, and taking into account crew manhour considerations, propellant storage, orbital transfer vehicle maintenance requirements, and orbital mechanics, UTMD arrived at a design for the facility. The amount of activity directly related to supporting Lunar base traffic is too high to allow the transportation hub to be part of the NASA Space Station. Instead, a separate structure should be constructed and dedicated to handling all transportation-related duties. UTMD found that the structure (named "Gateway") would need a permanent crew of four to perform maintenance tasks on the orbital transfer and orbital maneuvering vehicles and to transfer payload from launch vehicles to the orbital transfer vehicles. In addition, quarters for four more persons should be allocated for temporary accommodation of Lunar base crew passing through Gateway. Six orbit transfer vehicle(OTV) missions (2 vehicles per mission) are expected each year during the first ten years of Lunar base operation. Enough propellant must be kept on board to accommodate the OTV fuel requirements generated by this mission scenario. UTMD specified the amount of fuel storage needed and the number of remote manipulator arms to accommodate the refueling process and payload integration. An orbital inclination of 28.5 degrees was selected to allow the Space Shuttle access from Kennedy Space Center. The structure should be placed in a circular orbit between 240 and 260 nautical miles altitude. A Delta Truss structure was recommended as the framework for the individual components, primarily because of its resistance to damage after heavy docking activity and its ability to make orbital maneuvers such as a possible plane change or altitude boost. UTMD was careful to recommend an expandable structure that can adapt to meet the growing demands of the American space program as it moves toward the twenty-first century.

ACKNOWLEDGEMENT

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Finally, a very special thank you to Dr. Wallace T. Fowler for developing the ASE 274 Mission Design class into such a fine learning experience for the students.

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DEFINITION OF TERMS AND ACRONYMS

Term	Definition
ASE	-Aerospace Engineering
CETF	-Critical Evaluation Task Force
Delta V	-Change in Velocity of a spacecraft
ECLSS	-Environmental Control/Life Support Systems
ESA	-European Space Agency
EVA	-Extra Vehicular Activity
ft/sec	-feet per second
FORTRAN	-Scientific/Engineering Computer Language
IVA	-Intra Vehicular Activity
Gateway	-Earth transportation node
GEO	-Geosynchronous Orbit
H2	-Hydrogen Molecule
H2O	-Water
HLLV	-Heavy Lift Launch Vehicle
IOC	-Initial Operation Configuration
J2	-Orbital perturbation due to oblateness of Earth
JSC	-Johnson Space Center
km	-kilometers
KSC	-Kennedy Space Center
LBSS	-Lunar Base Systems Study
LEO	-Low Earth Orbit
LH2	-Liquid Hydrogen
LLO	-Low Lunar Orbit
LM	-Lunar Module
LO2	-Liquid Oxygen
LOX	-Lunar Oxygen
LSPI	-Large Scale Projects Institute
LSS	-Large Space Structure
Lunar Base	-Operational Facility on Lunar Surface
MHS	-Man-Hours
MLI	-Multilayer Insulation
MRMS	-Mobile Remote Manipulator System
MRS	-Mobile Remote Servicer
NASA	-National Aeronautics and Space Administration
NASA Space Station	-Currently Planned Space Station
NM	-Nautical Mile
O2	-Oxygen Molecules
ODT	-Orbit Determination Team
ODP	-Orbit Determination Program
OMV	-Orbital Maneuvering Vehicle
OTV	-Orbital Transfer Vehicle
PMAD	-Power Management and Distribution
PV	-Photovoltaic
RMS	-Remote Manipulator System
SD	-Solar Dynamic
UNIX	-AT&T Bell Labs. Operating System
UTMD	-University of Texas Mission Design
VAX	-High Speed Digital Computer
VCS	-Vapor-Cooled Shield

1.0 INTRODUCTION

The Advanced Programs Office at Johnson Space Center in Houston, Texas has decided to begin the construction of a permanent Lunar Base around the year 2000. The facility will require the transport of hundreds of metric tons of habitats, laboratory equipment, rover vehicles, and many other components to the Lunar surface. Rather than launching all of this mass directly from the Earth to the Moon using one vehicle, the payload will be transferred from the booster vehicle to another while in Earth orbit. Several designs for orbit transfer vehicles which can take the payload from Earth orbit to Lunar orbit have been proposed. These orbital transfer vehicles will require a maintenance and refueling facility in Earth orbit. University of Texas Mission Design (UTMD) studied the requirements of such a facility to best serve the needs of the Lunar base, while allowing expandability to accommodate future demands of interplanetary missions.

1.1 Project Statement

The operation of the Lunar base will not be possible without a transportation node in Earth orbit. A facility of this type should be tailored specifically to accommodate the needs of the base in terms of fuel storage, vehicle maintenance equipment, vehicle hangars, payload transfer equipment, and crew habitats. It should be designed to allow expandability as traffic to and from the Moon increases, particularly if the production of Lunar liquid oxygen becomes economical. The orbit of the transportation node should allow a large number of departure opportunities to possible Lunar destinations and be within reach of the launch vehicles, while not requiring excessive fuel to maintain altitude.

1.2 Problem Background

One of the primary goals of UTMD during the course of the research was to design the transportation facility such that the American space program could benefit as much as possible from the recommendation. This required UTMD to explore such options as making the transportation facility a part of the NASA Space Station structure, or designing the node to be a free-flyer in the proximity (less than 2 kilometers) of the Space Station, or perhaps building a new structure that is dedicated to transportation duties. The latter option offers the added advantage of freeing the Space Station from the frequent docking disturbances that heavy traffic flow will introduce into the microgravity research environment. UTMD has been careful in selecting the components for the transportation facility so that the anticipated growth of the space program will be accommodated.

1.3 Major Assumptions

Before undertaking the task of determining the orbit and outlining the growth process of Gateway, UTMD made several assumptions to ensure the feasibility of building Gateway. The primary reason for making these assumptions was to exclude any dependence on nonexistent technologies that may not exist before the beginning of the Lunar base. The assumptions were made as follows:

The United States will build a Lunar Base. The Lunar Base will not differ greatly from those proposed in 1987.

This study concentrated on the requirements that a Lunar Base will place on an Earth-orbiting station. The information made available by NASA and Eagle Engineering of Houston will serve as the driver for Lunar Base requirements. The design of Gateway is tailored specifically to accommodate these demands; including crew quarters, OTV service facilities, and propellant storage tanks.

Launch vehicle capabilities will not change dramatically before Gateway is constructed.

The calculations used to determine the orbit of Gateway relied heavily on specifications of operational or near-operational launch vehicles. A dramatic improvement in launch vehicle performance would almost certainly allow Gateway to be placed in a higher orbit than that selected by UTMD.

Orbital Transfer Vehicles (OTV's) will be built. The OTV's will perform close to the specifications available today. The maintenance requirements for the OTV's will not differ greatly from the figures available today.

At the present time, no OTV has been tested in space. The Earth to Moon transportation network being considered is dependent on some type of vehicle to transfer crew and cargo between Gateway and a Lunar orbit. The OTV's that have been proposed are reusable and require maintenance while in space.

The United States Space Station will be functioning before Gateway is constructed.

This is primarily a political and monetary issue. If an American research facility is not yet in orbit, it should be given priority over a dedicated transportation node such as Gateway.

1.4 Approach to the Problem

Because the Lunar base is likely to produce a high volume of traffic flow before the first manned interplanetary missions are started, UTMD chose to use available Lunar base buildup scenarios to generate the requirements that will be placed on the transportation hub. The analysis of the Lunar base scenarios yielded the expected number of orbital transfer vehicle (OTV) flights per year and the number of Heavy Lift Launch Vehicle (HLLV) and Space Shuttle flights needed to support the base. The number of OTV flights was used to determine the quantity of Orbital Maneuvering Vehicles (OMV's) needed on the transportation node, along with the required amount of hangar space and propellant storage. The total crew capacity and the permanent crew capacity were derived from this data and a study of allowable work loads for astronauts. The number of HLLV and Space Shuttle launches needed to construct the transportation hub was calculated considering standard space structure components (radiation shielding, attitude control, power supply, etc). Finally, such factors as Space Shuttle lift capabilities, atmospheric drag, and Earth launch site were included in an orbit determination computer program. The goal of the program was to select an orbit for the structure that maximized the departure opportunities from the transportation node to several possible Lunar destinations, while placing the structure in an orbit which did not require excessive reboosting. Gateway's orbit also had to remain within the useful range of the selected launch vehicles. From these analyses, UTMD selected both the structural requirements and possible orbit range for a transportation facility.

1.5 Results

Because of the anticipated role of the transportation facility in making travel to the Moon and outer planets feasible using current launch vehicle technology, the structure has been named GATEWAY.

UTMD determined that a separate transportation facility from the NASA Space Station should be constructed in order to support the Lunar base scenarios proposed in 1987. A permanent crew of four vehicle and payload integration specialists will be needed onboard Gateway. During the first ten years of Lunar base operation, approximately six OTV missions (2 OTV's per mission) per year will be initiated between Gateway and the Moon. Therefore, only two OTV's need to be housed and maintained at Gateway. In addition, one OMV will be needed for the proximity operations. UTMD elected to store enough liquid rocket propellant onboard Gateway to refuel two OTV's at any time. UTMD found that a Delta Truss will provide an excellent framework for the selected components. A total of four Shuttle flights and one HLLV flight will be needed to boost the structure into orbit and assemble the components. As Lunar base or interplanetary mission traffic demands increase, the Delta Truss can be expanded to accommodate more components than selected in this study. An artist's conception of Gateway is shown on the inside cover page of this report.

UTMD selected an orbit for Gateway based on approximately a 1995 technology baseline for launch vehicle capabilities. The altitude of the orbit is limited to 270 nautical miles because of the lifting capability of the Space Shuttle. The Delta Truss was used as a model to find a minimum altitude for Gateway. A minimum altitude of 210 nautical miles was selected. The inclination should be 28.5 degrees as long as Kennedy Space Center is the only Space Shuttle launch facility. Explanations of the individual topics of analysis that UTMD undertook are presented in the following sections of this report.

2.0 ORBIT DETERMINATION

UTMD was divided into two teams to approach the task of designing Gateway: an orbit determination team and an operations team. The proposed orbit for Gateway was chosen by the orbit determination team (ODT), although, initially, the desired characteristics for the orbit were established jointly by both design teams. The ODT then recommended a range of candidate orbits based on these assumptions and requirements.

Below is a description of the ODT goals, assumptions, considerations, and design tools. Also discussed are the Earth-Moon system and the proposed transportation networking. Orbit analysis having been completed, the conclusions and resulting orbit range choice will be presented in Section 2.7.

2.1 Goals of Orbit Determination Team

The objective of the orbit determination team was to determine an orbit for Gateway which satisfied the following criteria:

1) Accessibility to selected launch vehicles
2) Accessibility to Moon via Orbital Transfer Vehicles (OTV's)
3) Conservation of fuel for Earth-Moon transports

2.2 Major Orbital Assumptions

The following assumptions were made by the orbital design team in analyzing the orbit for Gateway:

1) Only the following launch vehicles were considered in this study
   - Space Shuttle
   - Shuttle-derived vehicles
   - Heavy Lift Launch Vehicles (HLLV)
   - These vehicles and the basis on which they were chosen will be discussed further in later sections.

2) To save fuel, aerobraking will be used by the OTV's upon return to Earth in order to reach LEO rendezvous with Shuttle or HLLV.

3) The Moon port orbit will be equatorial and approximately circular, otherwise the Lunar transfer will be directly to an equatorial Moon surface base.

The following factors also have a significant limiting effect on the range of possible Gateway orbits:

1) The inclination of the Moon varies between 18.19° to 28.35°.

2) The Shuttle can presently be launched only from Kennedy Space Center, and is capable of only ≈ 0.5° of plane change.

3) The Shuttle, Shuttle-derived vehicles, and HLLV cannot place a large payload beyond LEO.

2.3 Transportation Network

The driving theme behind Gateway is that of a transportation node to support the build up of the Lunar base. Gateway would the hub of a transportation system utilizing two types of vehicles: launch vehicles, designed mainly to bring a payload up through the atmosphere and Orbital Transfer Vehicles (OTV's), constructed mainly for non-atmospheric travel although some designs incorporate an aerobrake for a return trip to Earth. The concept detailed below in Figure 2-1 is the current scenario for the transportation network.

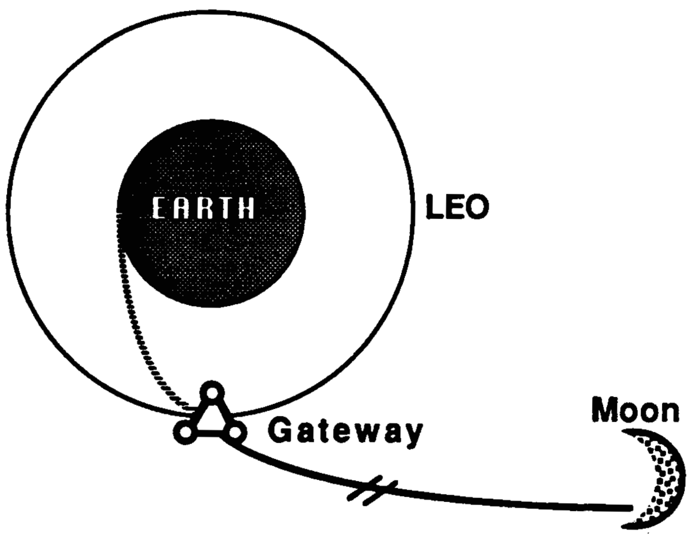


Figure 2-1 Transportation Network

2.3.1 Launch Vehicles

All launch vehicles considered for use on Gateway were either currently operational or in a stage of development that would allow for a 1995 launch date. Only vehicles being developed in the United States were given consideration. Available information on a wide range of launch vehicles was collected to form a data base of launch vehicles.

Launch Vehicle Data Base

Information from Large Scale Programs Institute (LSPI) along with other sources was condensed into the Launch Vehicle Data Base shown in Appendix C. This was used in the Gateway sizing process and in Gateway's orbit determination. Two launch vehicles were chosen to support Gateway; the Space Shuttle and a Heavy Lift Launch Vehicle(HLLV).

Space Shuttle

The Space Shuttle is the only available launch vehicle with crew transportation capabilities. Since the mission scenario requires accommodation of both crew in Gateway and crew through Gateway, a vehicle with crew capability was mandatory. The Space Shuttle's lift capabilities are shown in Figure 2-2.

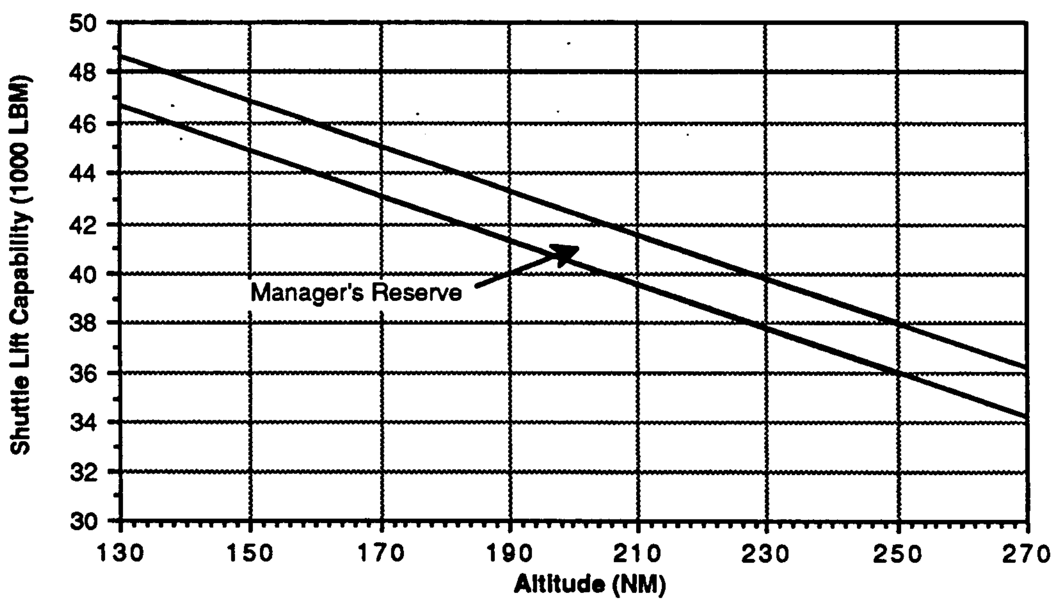


Figure 2-2 Shuttle Lift Capability vs Altitude [28]

HLLV

The primary launch vehicle to support Gateway will be the HLLV. Several HLLV's are in development at this time with a payload capacity of approximately 100 metric tons to LEO. Payload and crew support launches being considered by our sizing process in support of Gateway consist of a combination of Shuttle flights and HLLV flights.

2.3.2 Launch Sites

Geographic considerations are:
1) No launches which can endanger a populated area
2) Body of water required to ditch tanks or boosters.

Launch sites considered were Kennedy Space Center (KSC), Hawaii, and French Guiana in South America. KSC is the only current launch site capable of launching the Space Shuttle. Hawaii was considered because it is geographically the lowest point in the U.S. at a latitude of approximately 20 ° North. Politicians and business people in Hawaii are actively pursuing government approval to begin construction on a Hawaiian launch facility. Since the plane of the Moon varies from a latitude of 18.5 ° to 28.5 °, the maximum required plane change from Hawaii is approximately 2°. French Guiana is currently a launch site for the European Space Agency (ESA). French Guiana has very close to an equatorial latitude and would involve no plane change for virtually any orbit.

2.3.3 Description of the Earth-Moon System

Strictly speaking, the Moon does not orbit the Earth; to be more precise, the Earth and Moon revolve about their common center of mass approximately once every 27.3 days. There is actually a maximum 7 hour variation due to solar perturbations. This center of mass of the Earth-Moon system then revolves around the sun at the rate of one revolution per year. Because the mass of the Earth is 81.3 times that of the Moon and the mean distance between the two is 384,400 km, the center of mass of the system lies 4,671 km from the center of the Earth.[25] Mean orbital elements for the Moon are as follows:

Parameter	Value
Semi-major axis	384,400 km
Eccentricity	0.054900489
Inclination (to ecliptic)	5°8'

The argument of perigee changes in the direction of the Moon's orbital motion by 360° over a time period of about 8.9 years. Since the period of the Moon with respect to the Earth is the same as its period of rotation about its own axis, it maintains roughly the same orientation with respect to the Earth at all times.

2.4 *Other Considerations*

2.4.1 Safety

There are several orbit considerations that are strictly a matter of safety.

These include orbital debris, the Van Allen radiation belts, and cosmic radiation and solar flares. Orbital debris represents a significant safety concern for any type of permanent space structure. The amount of debris has escalated at the rate of ≈ 13%/yr since 1966. Intercollisions among debris in orbit produce smaller debris capable of repeating this cycle. The real danger lies in the fact that most of these collisions will be "high energy" impacts [11]. The average impact velocity of 10 km/s ensures that almost all of the collisions will exhibit hypervelocity impact characteristics. Both objects will be subjected to very high instantaneous pressures with the strong shock waves causing melting and possible vaporization in the region of the hole.

Another safety consideration is the high intensity radiation bands that encircle the Earth. These two concentric belts are known as the inner Van Allen radiation belt and the outer Van Allen radiation belt. The inner belt stretches from about 500 to 2,500 miles at a latitude of +/- 20° with a maximum intensity occurring at about 1,800 miles. The outer belt has a range of 8,000 to 20,000 miles for latitudes of +/- 50 ° and peaks at about 12,000 miles.

Cosmic radiation and solar flares also present a potential health hazard to the crew. However, the chosen orbit range was just under the Van Allen Belts and, therefore, also below the influence of severe radiation so no more research was done in this area..

2.4.2 Atmospheric Drag

Since the drag forces exerted on the vehicle by the atmosphere increase as the orbit altitude decreases, and drag is inversely proportional to the mass of the vehicle,.the mass and surface area of the structure were key factors in determining an altitude for Gateway. A 90 day reboost requirement established the lower bound on altitude, where 90 days is the minimum time that Gateway must be able stay aloft without a reboost in the event of some failure.

The assumption for a nuclear safe orbit was an orbit such that the structure would not reenter for a period of 200 years, allowing time after a nuclear accident or meltdown to somehow boost the defunct structure into a higher orbit.

2.5 Orbit Analysis

Two software packages were written to generate the data on which the final orbit recommendations were based. On the VAX, a FORTRAN program was written to model the delta V's required for each segment of the transportation network, while on the Macintosh, a TK!Solver model was created to find departure windows from LEO to the Moon.

2.5.1 Delta V Analysis

The program is designed to be interactive and has been written in UNIX environment. A top-down look at the orbit analysis software is shown in Figure 2-3. Delta V's for each segment of transportation system were calculated in their respective subroutines. The list of inputs includes the following:

1) Altitude range and step size
2) Inclination of Gateway's orbit
3) Launch site
4) Operational date
5) CD, area, & mass of Gateway
6) Vehicle parameters

The operational date here is required to generate departure windows to the Moon from LEO and is based upon an equatorial Lunar orbit or equatorial Lunar base.

Program outputs took the form of the following plots:

1) Delta V vs. Altitude
2) Launch Windows Per Year vs. Altitude
3) Delta V vs Mass of Fuel

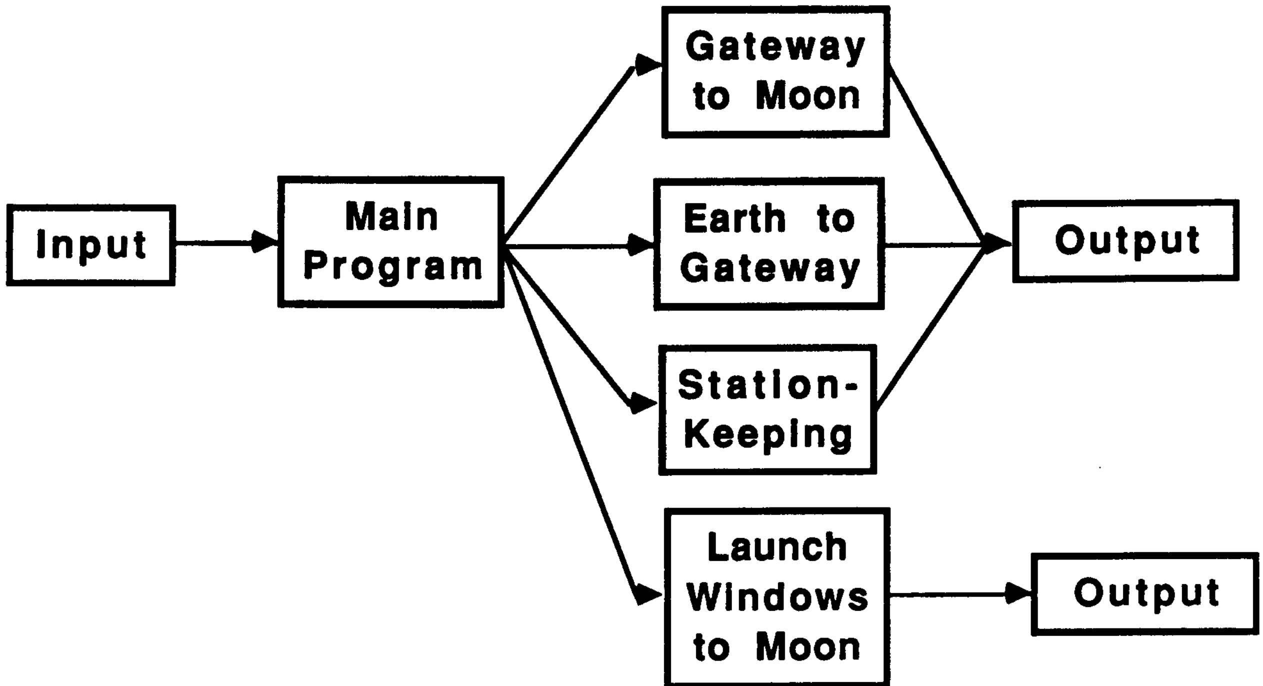


Figure 2-3 Orbit Determination Program Top Down Diagram

2.5.2 Launch Window Determination

One of the major considerations in the selection of a Gateway orbit was frequent access to and from both the Earth and the Moon. Since Gateway was constrained by shuttle limits to a Low Earth Orbit (LEO), access from the Earth should not pose a problem. At LEO, Gateway will have a relatively high precession rate and should pass over head several times a day. Therefore, the launch windows that needed to be studied in more detail were those between the Gateway and the Moon. In order to do this, the Lunar destination was first considered.

It was much too time consuming to examine launch windows between all possible Gateway orbits and all possible lunar destinations, therefore, the cases investigated were limited to Gateway inclinations of 18.15°, 23.5°, 28.5° at an altitude range of 100 km to 2000 km. Five lunar destinations were chosen for study, four to a possible Moon Port and one to a lunar equatorial orbit where a lunar hopper would rendezvous with the OTV from Gateway and take the payload to an equatorial Lunar base[22]. In order to conduct the launch window analysis, a mathematical model was developed using TK!Solver, a commercial equation solving program that is available for both IBM and Macintosh personal computers. The model used the J2 perturbations of the Earth to calculate the nodal regression of Gateway and a triaxial model of the Moon to calculate the regression of the

Moon Port orbit[8]. Also considered was the precession of the Earth-Moon line and, to simplify the analysis, the orbits of Gateway and the Moon were assumed to be in the same plane. A more accurate model using Solar perturbations and other gravitational effects of both the Earth and Moon could be created involving considerably more work, but the final results for launch windows per year would not change significantly.

The results from the lunar base studies showed that there will be approximately 6 to 9 OTV flights per year through Gateway. This constraint virtually eliminated the possibility of using a Moon Port unless the Gateway is in as low an orbit as possible. This constraint can easily be met from any Gateway altitude to a lunar equatorial orbit however, UTMD has decided to recommend that there be no Moon Port unless the Gateway orbit is in a LEO instead of a near GEO location. Our final analysis placed Gateway in LEO, so an equatorial Moon Port will not introduce any significant departure window constraints.

2.6 Integration with Structures Team

The orbit determination team interfaced with the structures team at several points of the orbit design phase. Initially, the structures and orbit determination teams combined to determine preliminary orbit assumptions. After orbit analysis progressed sufficiently, other parameters such as as mass and area of the structure were required from the structures team; then the final plots based on this data were produced.

2.7 Orbit Recommendation

The orbit determination team will propose an orbit for Gateway which (1) is accessible to selected launch vehicles, (2) allows access to Moon via OTV, and (3) is fuel efficient for Earth-Moon transfers.

2.7.1 Launch Windows to Moon

The results show that the existence of a Moon Port could significantly reduces the number of available launch windows. An equatorial Moon base yields the highest number of launch windows and a polar orbiting Moon Port the least. This can be seen in Figure 2-4 which is for a Gateway inclination of 28.5°. These results show that the existence of a Moon Port definitely has a detrimental effect on launch windows. A Moon Port orbit locked with respect to the Earth would be highly desirable as it would improve launch opportunities and allow for more flexibility in the selection of a lunar base site. On the basis of departure opportunities, an equatorial lunar base would be the obvious choice. However, mineral or other resources on the Moon may override the importance of departure window opportunities and should also be considered in the selection of a lunar base site.

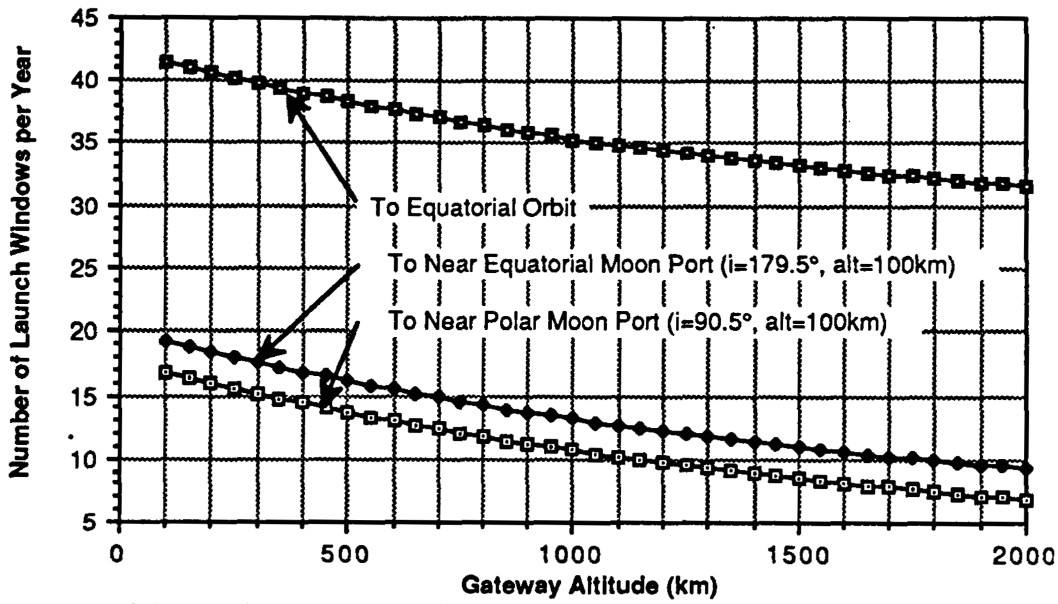


Figure 2-4 Results for Gateway at 28.5° inclination

For each of the five cases that were examined, the inclination of Gateway had very little effect. As can be seen in Figure 2-5 the number of launch windows gained by lowering the Gateway orbit from 28.5° to 18.15° was always less than 2. This was true for all of the cases considered; the effects of Gateway altitude were more important. For each of the five cases a Gateway at 2000 km would generally have 10 less launch windows per year than a Gateway at 100 km altitude. The overall trend is as expected: a lower inclination and a lower altitude for Gateway yield more frequent launch windows than higher inclinations and altitudes.

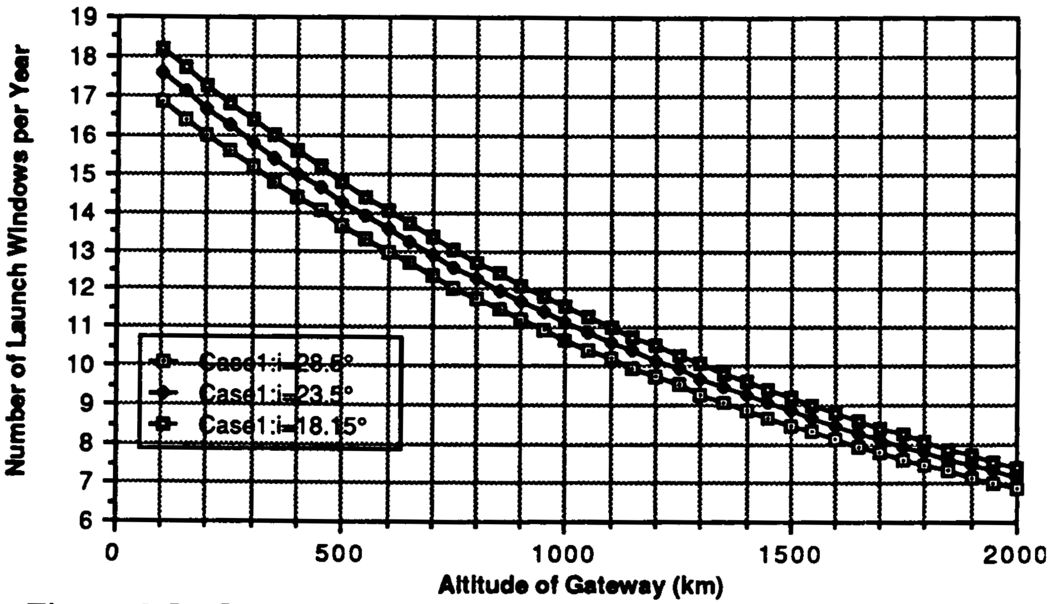


Figure 2-5 Case 1-Near Polar Moon Port (i=90.5°, alt=100 km)

2.7.2 Delta V: Reboost

The orbital software designed to do the reboost segment of the Orbit Determination Program calculated the delta V required to do a Hohmann transfer back to the original altitude for a vector propagated to some final time. The propagation accounted for atmospheric drag and J2 effects. For different altitudes propagated to the same final time, the reboost curve delta V in Figure 2-6 fluctuated rather dramatically and seemed to correspond to the periodic variations in semi-major axis due to the oblateness of the Earth. Since these changes in semi-major axis are functions of orbital period, the final propagation time was adjusted to the nearest multiple of the orbital period. Running this case produced the smooth delta V' curve also found in Figure 2-6.

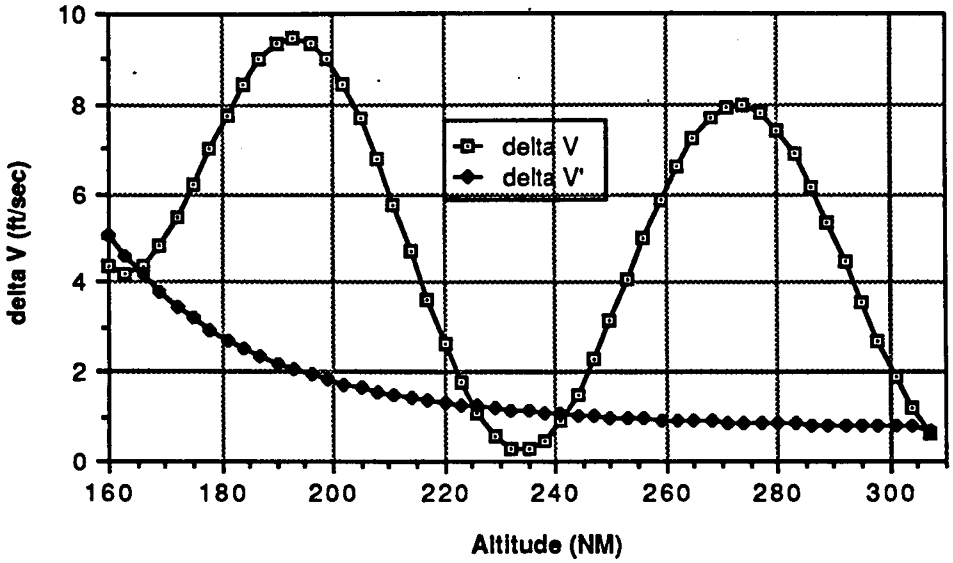


Figure 2-6 Reboost Delta V for One Day

When the vector was propagated for 90 days to satisfy the reboost constraint, as seen in Figure 2-7, similar fluctuating trends became evident though, as expected, they were of a much smaller magnitude than before.

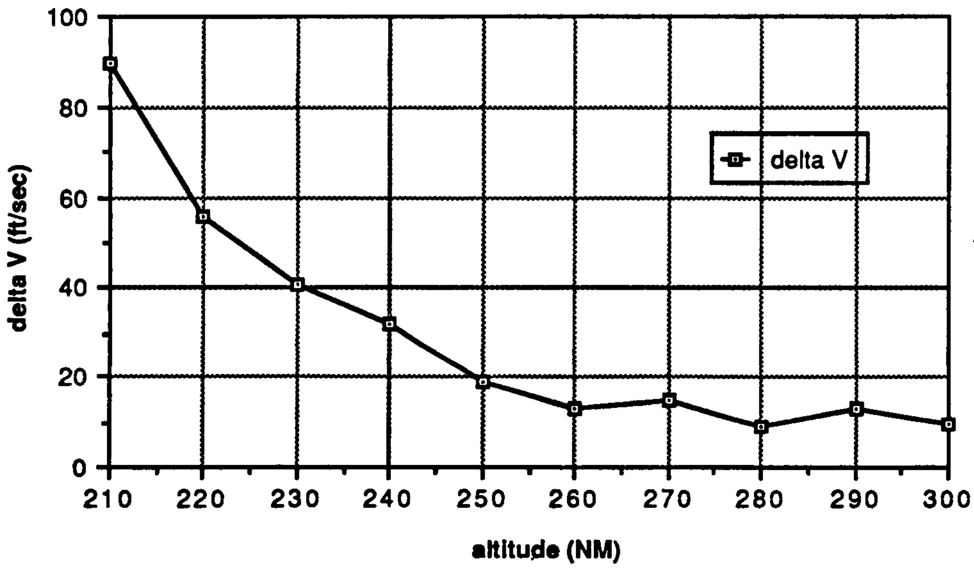


Figure 2-7 Reboost Delta V for Ninety Days

The different mass cases were also propagated for 3 months, as seen in Figure 2-8, with the lighter mass deorbiting more quickly than the loaded structure. Since drag is inversely proportional to mass, this was to be expected.

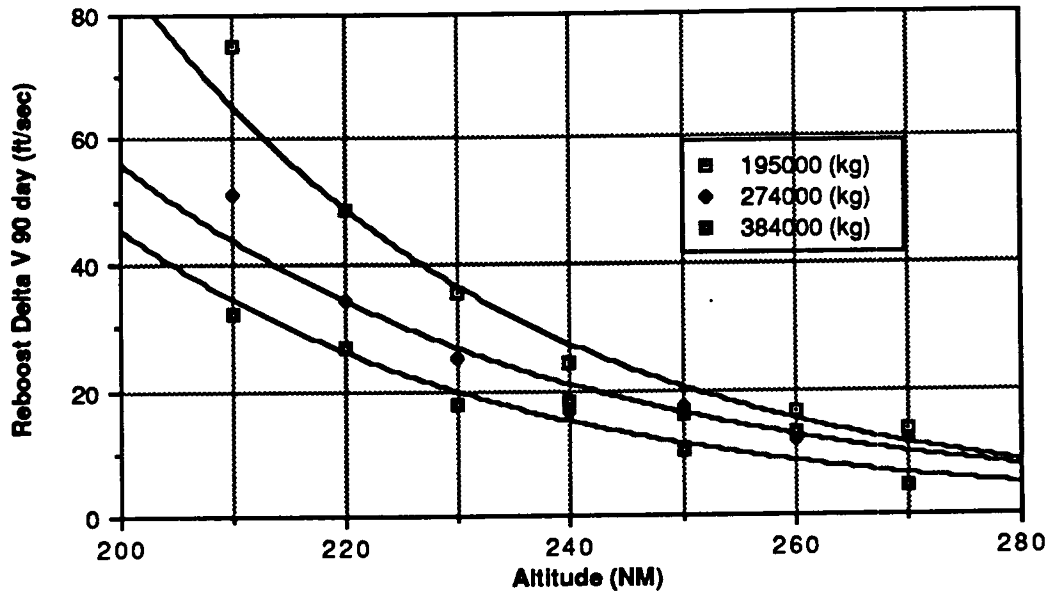


Figure 2-8 Reboost Delta V's for Ninety Days

Figure 2-9 shows the daily reboost delta V with the three different mass cases. These were also run for a final time adjusted to the nearest multiple of the orbital period.

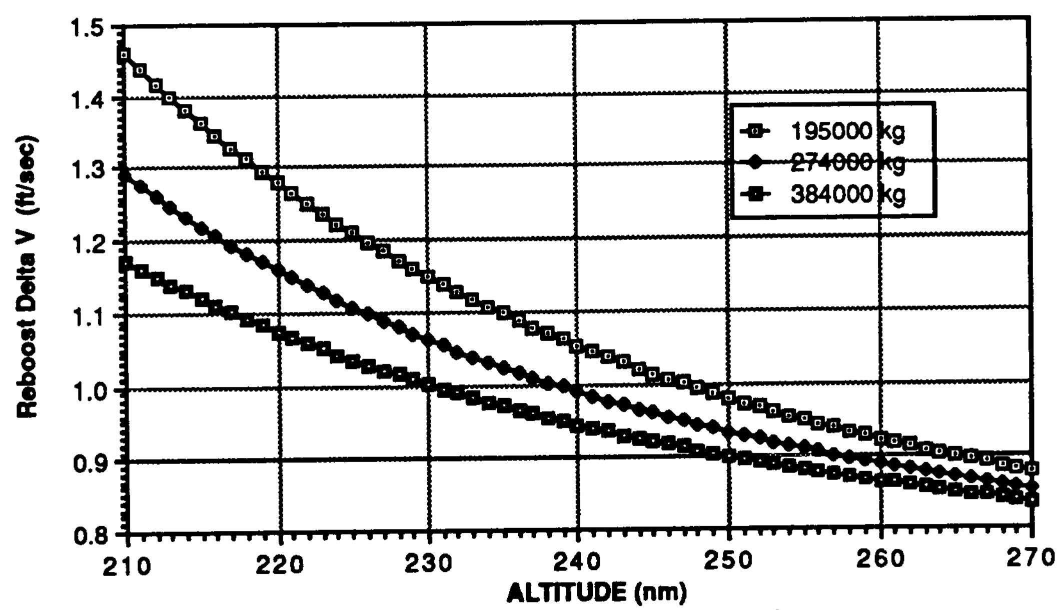


Figure 2-9 Daily Reboost Delta V's

Figure 2-10 shows the daily reboost delta V with the three different mass cases. These were also run for a final time adjusted to the nearest multiple of the orbital period.

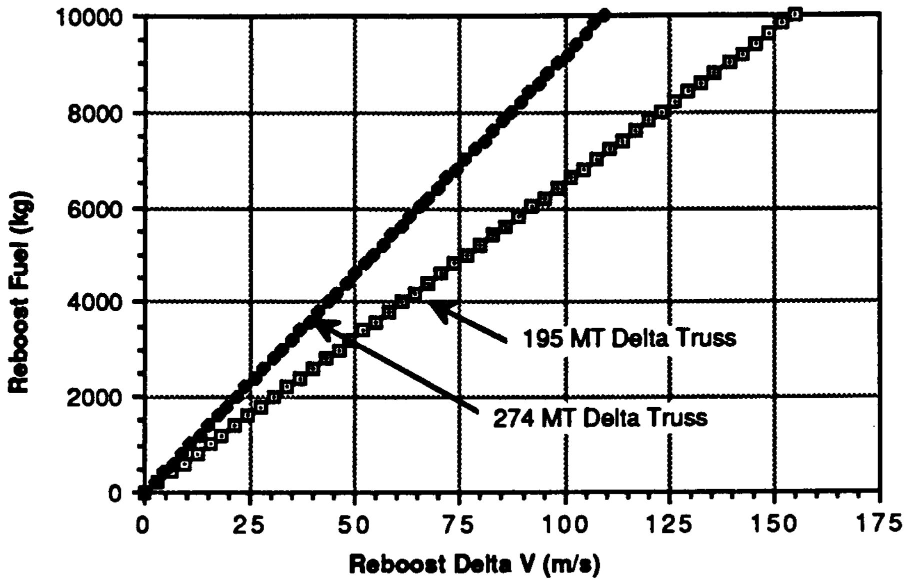


Figure 2-10 Reboost Fuel Mass vs Delta V

2.7.3 Delta V: Earth to Gateway

The following plot in Figure 2-11 is a very basic model of the Earth to Gateway delta V. The algorithm only accounts for w_{earth}, velocity lost due to potential energy gain, and the velocity necessary to attain circular orbit. Even with these crude simplifications, the model is within 10% of the real values.

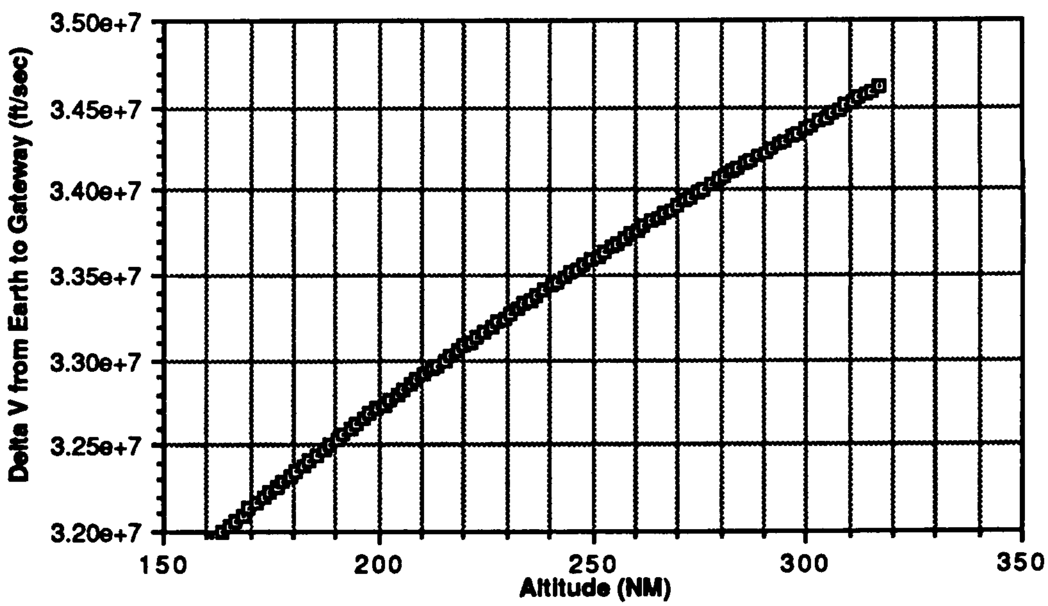


Figure 2-11 Earth-Gateway Delta V

2.7.4 Delta V: Gateway to Moon

The Gateway to Moon delta V was approximated using a modified patched conic [25]. The Apollo 17 numbers were used to verify the accuracy of the model. Although the downward tendencies of the delta V curve with increasing altitude are obvious, the magnitude of the trend is too small to have a direct effect on an altitude range for Gateway.

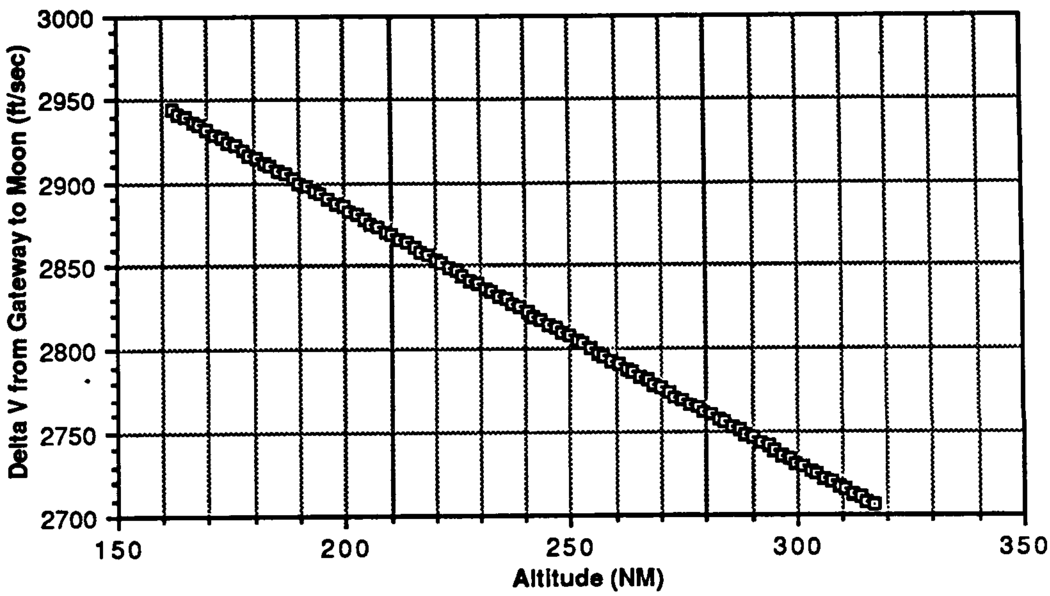


Figure 2-12 Gateway-Moon Delta V

2.7.5 Conclusions

After applying the orbital assumptions and other considerations listed in Sections 2.2, the orbit determination team narrowed the orbit range of interest: the orbital parameter ranges along with the corresponding justification are presented below in Table 1.

Table 2-1 Orbital Range for Gateway

Gateway Orbital Parameters Reasoning		Restriction
Semi-major axis (a)	Max Altitude 270 nm	Shuttle to orbit with significant payload
Semi-major axis (a)	Min Altitude 210 nm	Must remain aloft for 90 days without reboost
Inclination (i)	28.5°	Operational Launch Sites for Shuttle
FINAL ORBIT RANGE	240 TO 260 NM	BEST COMPROMISE BETWEEN SHUTTLE LIFT CAPABILITY AND REBOOST REQUIREMENTS

3.0 GATEWAY SIZING PROCESS

The primary mission requirement of Gateway is to function as a transportation node in Earth orbit. The objective of this section is to determine Gateway's structural requirements. Both the Initial Operation Configuration (IOC) and subsequent yearly development are to be delineated. Since Gateway's configuration depends heavily on storage and manpower projections, defining a projected traffic model is the initial step in defining the station's requirements.

3.1 Traffic Model

An accurate estimate of the vehicle activity needed to transfer crew and payload either to or from the Lunar base is essential in the sizing process. Manpower and storage requirements necessary to support this traffic will determine Gateway's configuration. Items of primary concern include:

1. Number of flights per year for Launch Vehicles and Orbit Transfer Vehicles.
2. Payload mass and crew throughput per year from Earth surface to destination orbit.
3. Amount of liquid propellant usage per year.

3.1.1 Missions Considered

The two sources of traffic that Gateway needs to accommodate are interplanetary missions and Lunar Base build-up and support missions. However, it is assumed that during Gateway's first ten years the Lunar Base missions will provide the heaviest traffic through Gateway and that the interplanetary missions will have little impact on the traffic model.

3.1.2 Lunar Base Scenarios

Baseline Scenario

The Advanced Programs Office at Johnson Space Center (JSC) has been working on three different Lunar Base scenarios: (1) emphasis on science, (2) emphasis on resources, and

(3) emphasis on habitation. Currently, the only study available is the science study released in December 1987. An important assumption that dictates the traffic model is that the study assumes a continuous build-up of the Lunar Base from 1998 to 2020. Although this baseline scenario has an emphasis on scientific activities, it also assumes that Liquid Oxygen (LOX) production on the Lunar surface is feasible. Therefore, the study assumes a heavy production of LOX after the first decade of base activities. This requires a large amount of crew and payload support. However, if LOX production has been determined unfeasible, the Lunar Base traffic and payload schedules are expected to level out.

Alternative Scenario

Because of the uncertainty regarding what Lunar Base scenario will be used, an alternative study to the JSC scenario was also modelled. An alternative study would provide insight in identifying those Gateway systems that may be affected by a different Lunar Base scenario. This will also help identify those Gateway systems that will need to be more flexible for Gateway expansion.

The alternative study used was the Lunar Base study by Eagle Engineering, Inc., also released in December 1987. For each year the report determines the amount of Lunar crew needed, the total payload weight to Low Lunar Orbit (LLO) and the number of manned and unmanned missions. Its major emphasis is on science. The report also assumes that each manned OTV mission will have a total of four Lunar crew members. The primary difference between the Eagle scenario and the JSC scenario is that the Eagle scenario has a initial build-up phase from 1998 to 2005 while the JSC scenario plans for a continuous build-up from 1998 to 2020. Other differences are that the report assumes one basic type of Lunar Module (LM), an expendable lander/ascent vehicle, for delivering cargo and crew to the base during the entire six year build-up phase. After the sixth year, some reference is made to using a reusable lander that is stationed at the Lunar Base. It uses the LOX produced by a LOX plant if production proves to be feasible.

3.1.3 Method of Analysis

The tool used in determining the traffic model was the Lunar Base Model software developed by the Large Scale Programs Institute (LSPI). The user of the software devises a Lunar Base scenario and selects various technology options. The software then determines the support infrastructure and required crew for Lunar Base operations. The user defines a transportation fleet. After several iterations between the user and the software, a flight schedule, mass throughput schedule, and OTV/LM propellant usage schedule is determined.

The model assumes that the launch vehicles will launch from Kennedy Space Center. Propellant usage is based on the delta V's from the Apollo 17 mission. The model also assumes that the base is permanently manned and that a reusable lander is housed at the Lunar Base. It also assumes that each manned OTV mission will have a crew of four to six Lunar crew members.

LSPI has already entered the JSC baseline scenario into the software model.and has determined a representative traffic model. Figure 3-1 shows the amount of mass that needs to be delivered to LLO and the propellant mass that needs to be delivered to Gateway.

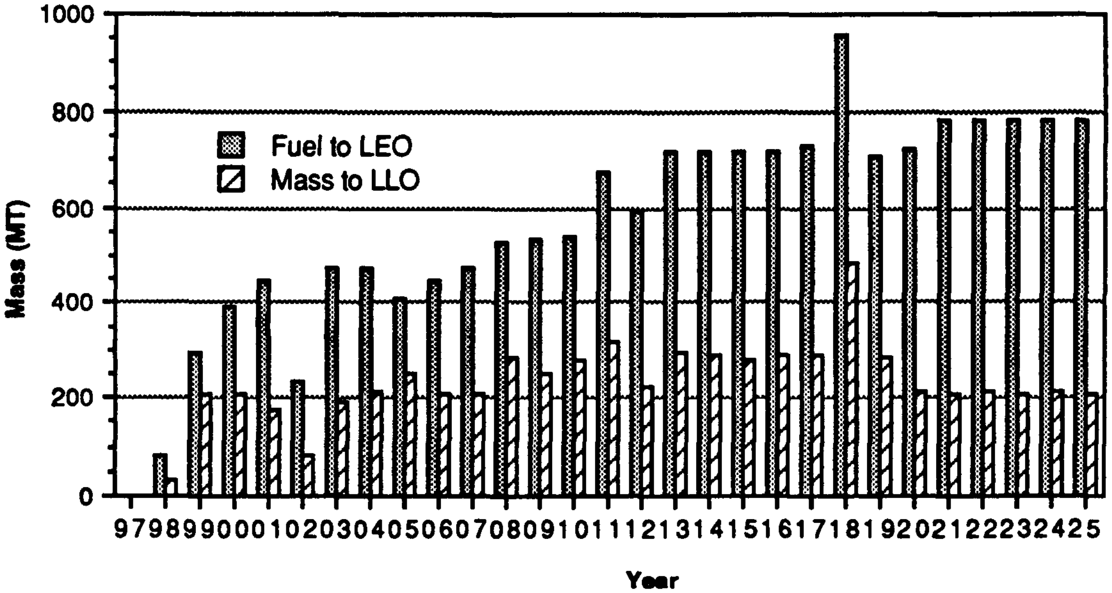


Figure 3-1 Mass Schedule for JSC Scenario

After the year 2010, the OTV flight schedule, Figure 3-2, increases due to the increase in the manpower requirement for the operation of the LOX production plant. If LOX production is proven unfeasible, the OTV flight schedule can assume to maximize at approximately six flights per year.

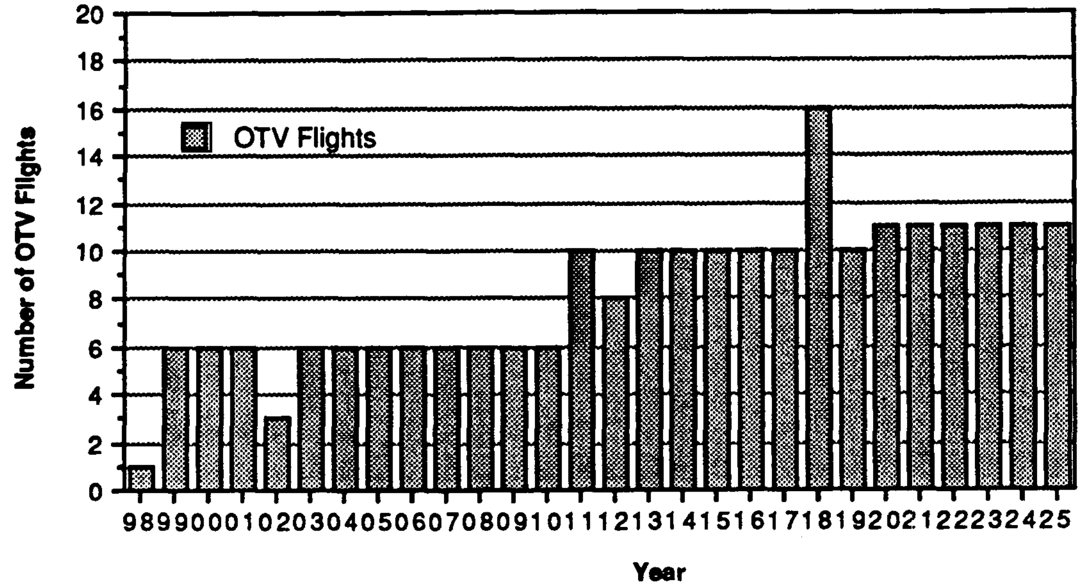


Figure 3-2 OTV Flight Schedule for JSC Scenario

Figure 3-3 shows that before 2011, the number of Shuttle flights and HLLV flights peak to six flights and five flights per year, respectively. Again, the large increase in Launches after 2010 is due to the support required for the Lunar LOX production plant.

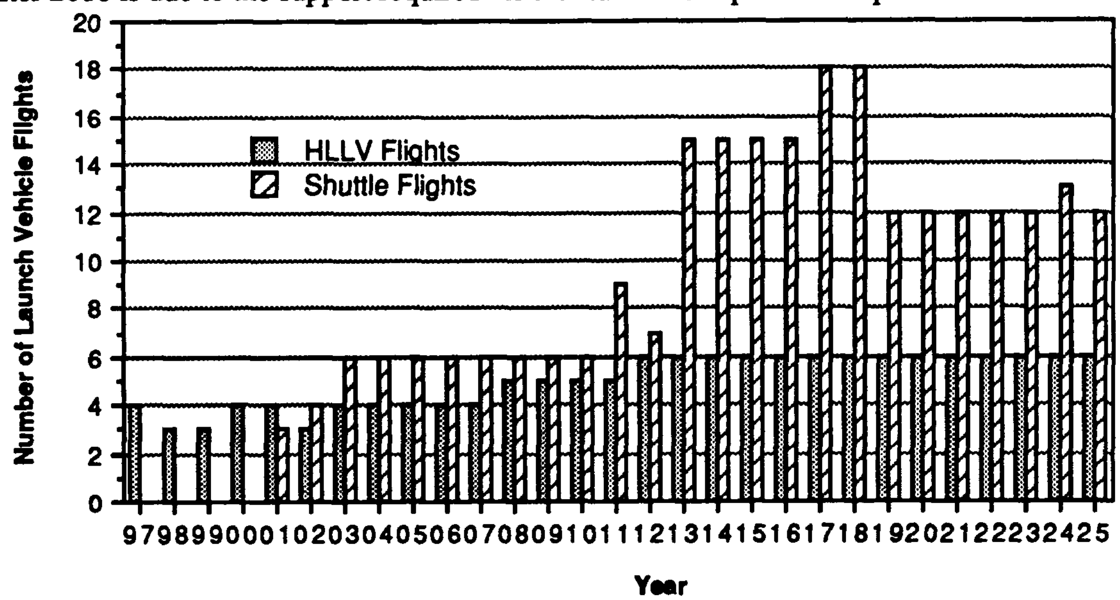


Figure 3-3 Launch Vehicle Flight Schedule for JSC Scenario

In order to mirror the Eagle report as closely as possible, some modifications to the LSPI software were needed. In addition, a problem had occurred when selecting the appropriate LM for the transportation fleet. The software only considers reusable LM's while the Eagle study, as mentioned before, uses an expendable lander/ascent LM. This difference slightly changes the true traffic model for the Eagle study. Because the Eagle study assumes a heavy initial base build-up from 1998 to 2005, as shown in Figure 3-4; the software model determined a more demanding traffic model.

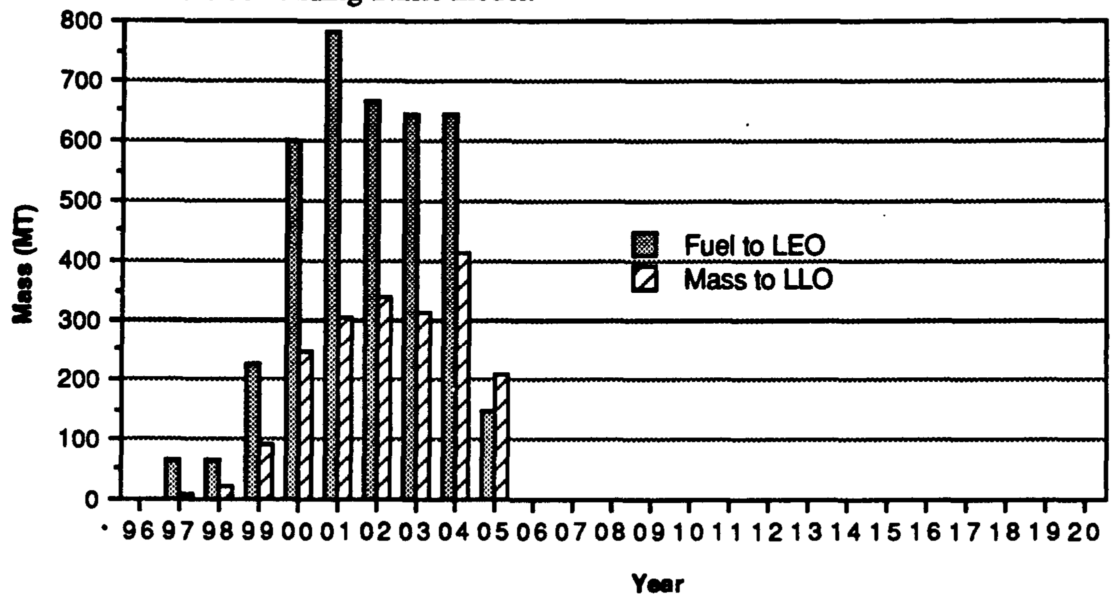


Figure 3-4 Mass Schedule for Eagle Scenario

Figure 3-5 shows the number of OTV flights for each year. The number of OTV flights for this scenario peaks at twelve by the year 2004.

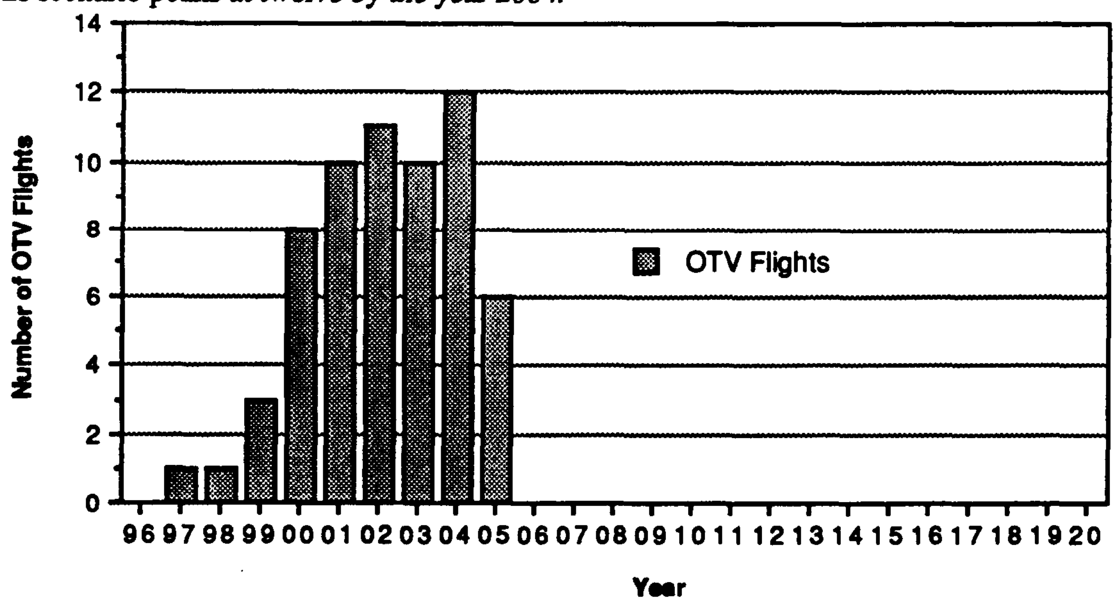


Figure 3-5 OTV Flight Schedule for Eagle Scenario

Figure 3-6 shows the launch vehicle flight schedule. The number of HLLV flights peaks at nine in the year 2000 while the number of Shuttle flights peaks at seven.

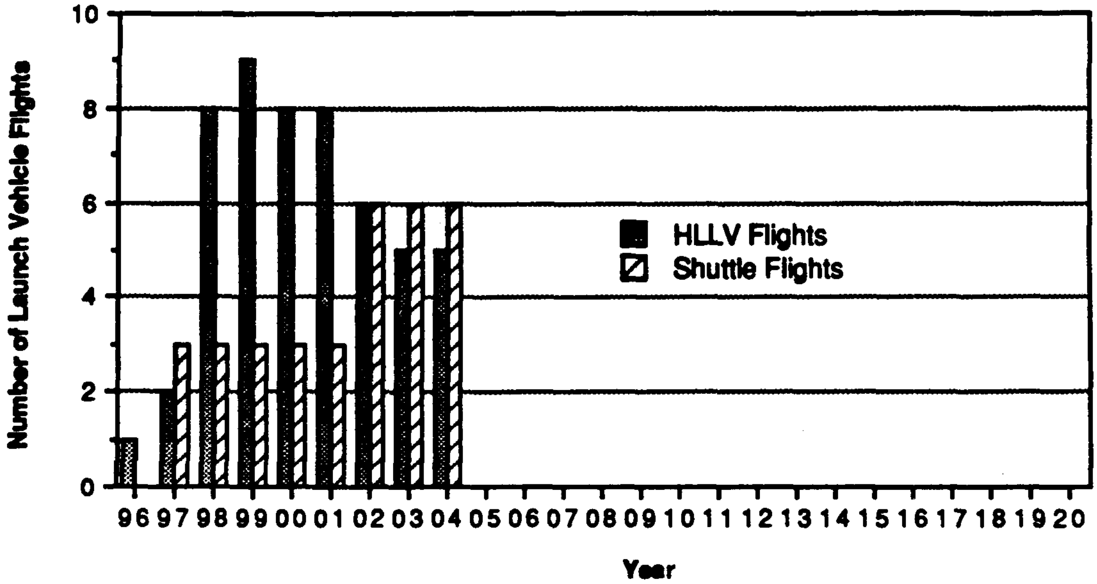


Figure 3-6 Launch Vehicle Schedule for Eagle Scenario

Lunar Base Systems Study (LBSS)

Another study done by the Advanced Programs Office at JSC has recently been released in March of 1988. The study was concerned with the timeframe from 2000 to 2005. The OTV flight schedule for this scenario, shown in Figure 3-7, shows that the maximum number of OTV flights is six per year, the same as the JSC baseline scenario.

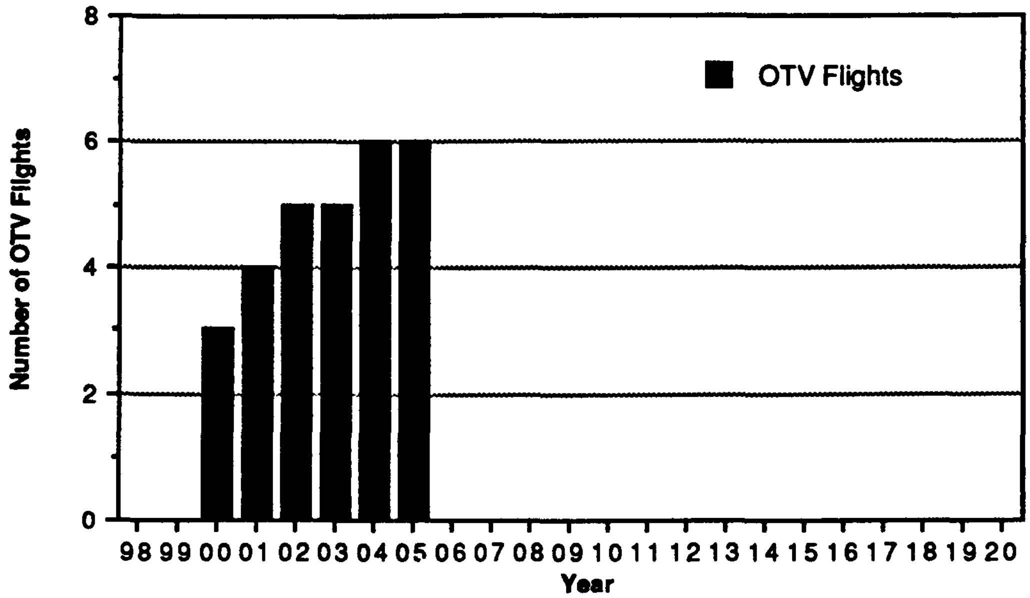


Figure 3-7 OTV Flight Schedule for LBSS Scenario

3.1.4 Traffic Study Conclusions

Several results have been determined from this traffic study. First of all, the traffic model is strongly dependent on the presence of a LOX production plant. In addition, the model is also dependent on the type of Lunar Base build-up scenario that is used. A heavy, initial build-up results in a more demanding schedule. However, the peak number of OTV flights in the JSC baseline scenario are the same as the peak number of OTV flights in the recently released Lunar Base Systems Study. Based on these traffic studies, it has been determined that Gateway should be able to accommodate a maximum of six OTV flights per year, it should be capable of storing a maximum of 110 MT of cryogenic fuel, and it should be able to accommodate four to six Lunar Base crew members at one time. In addition, Gateway should expect a maximum of six Shuttle launches and five HLLV launches per year.

3.2 OTV Fleet

Obtaining transfer vehicle requirements was complicated by the fact that no operational transfer vehicle exists. The missions to be supported by the transfer vehicle fleet include trips transporting crew and cargo to and from the Moons surface and to the Earths surface. A wide variety of transfer vehicles have been proposed to accomplish these missions.

Information on several different types of transfer vehicles was compiled into a data base from which a transfer vehicle fleet could be selected depending on the OTV mission scenario chosen to deliver the mass to and from Gateway.

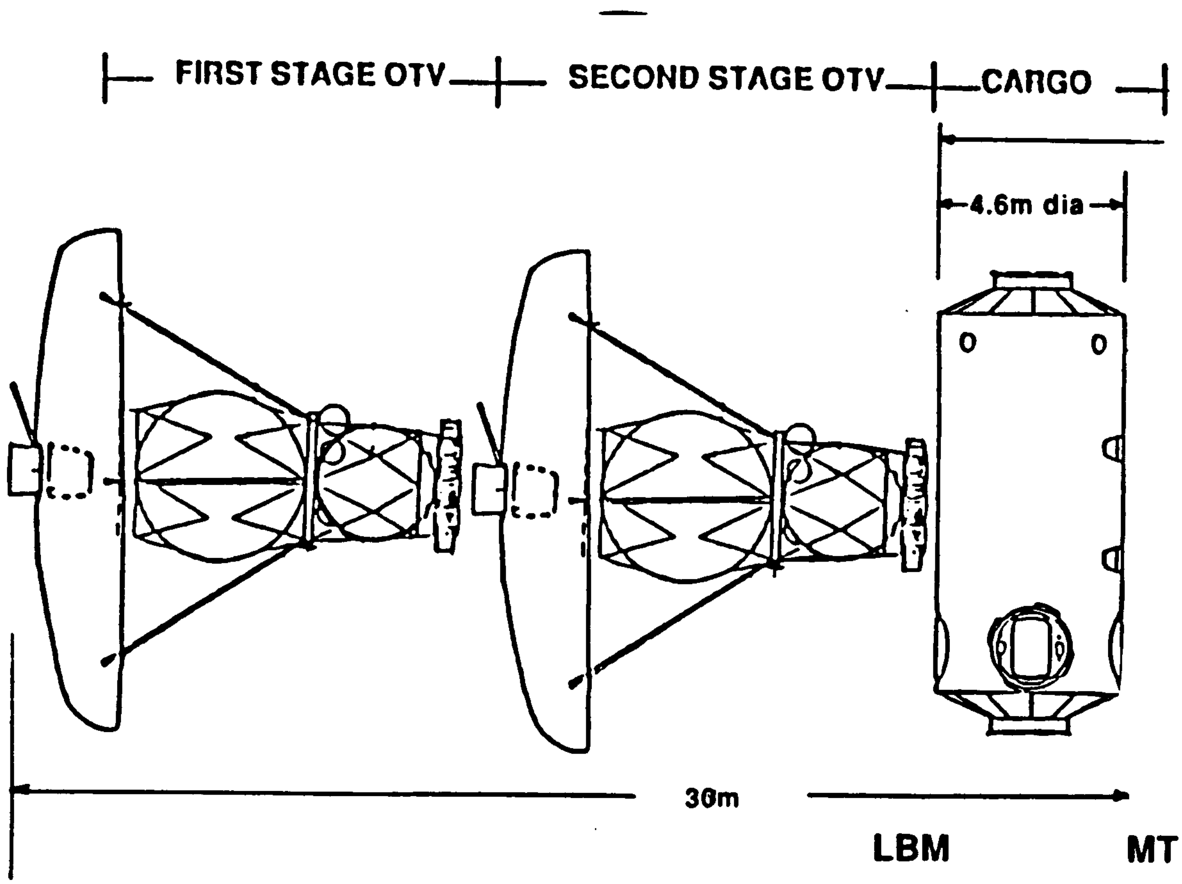
3.2.1 OTV Data Base

Gathering of available information provided the transfer vehicle capabilities shown in Appendix D. Capabilities were defined for both manned and unmanned transfer vehicles. Also listed are single and multistage reusable vehicles, and one-way slow transfer vehicles.

Two Staged OTV

The two staged OTV, both manned and unmanned versions, were chosen as Gateways transfer vehicle fleet. A two staged OTV is simply two single stage OTV's stacked together with a payload package (either manned or unmanned) attached to one end. The vehicle stack is launched clamped together. Once the first stage completes its section of the journey, it disengages from the stack and enters a return trajectory to Gateway. The second stage then engages and continues to complete the mission and return to Gateway with payload from the Moon. For each OTV mission, two OTV turnarounds must be completed, one for each stage. Figure 3-8 shows a possible configuration for the two staged OTV with payload. This diagram pictures each stage, complete with aerobrake shield, liquid hydrogen and liquid oxygen tanks, and payload.

Figure 3-8 General Dynamics Two Stage OTV Configuration [17]



	LBM	MT
FIRST STAGE WEIGHT	87,000 LBS.	39.5
SECOND STAGE WEIGHT	87,000 LBS.	39.5

Orbit Maneuvering Vehicle

Gateway will also be equipped with one OMV to perform all vehicle operations (except for shuttle docking) in the vicinity of Gateway. The OMV will utilize cold gas propellent considered safe for proximity operations. Its functions will include receiving incoming payloads and OTV's for taxi into Gateway, docking and maneuvering spacecraft on Gateway, and delivering outbound spacecraft and cargo safely away from Gateway before LH2/LO2 engine ignition. The OMV will have a range of approximately two miles.

3.2.2 OTV Requirements

Since Gateway will be the hub of a space based transportation network, requirements for transfer vehicles included not only payload capabilities and fuel usage, but also the maintenance, servicing, and resupply requirements listed in Appendix D.

Maintenance Facilities

It is assumed that all OTV maintenance will occur inside hanger facilities that are approximately twice the overall vehicle volume. It is also assumed that OTV storage space outside the hanger facilities can be utilized when maintenance is not occurring. Crew and maintenance equipment protection during maintenance procedures provides the primary motivation for this restriction. Gateway will be equipped with teleoperation capabilities. A combination of teleoperation and EVA will be used to perform maintenance tasks. OTV's will be docked on a rotating servicing fixture in the hangar facility. Two RMS arms will accompany each servicing fixture. Servicing tasks performed using teleoperation will involve one or two member IVA crews while three person crews consisting of one IVA and two EVA members will accomplish EVA tasks.

Turnaround Time

OTV turnaround time involves estimating in space maintenance time requirements for each transfer vehicle. This includes routine checks of all systems and on board equipment, repair of any damage that may have occurred, replacement of defective or worn out items, and refueling. A General Dynamics study on OTV turnaround operations provided a list of every turnaround task for a space based OTV and an estimate of the manhours to complete each task. With a combination of teleoperation and EVA to perform maintenance tasks, a routine OTV turnaround can be accomplished in 58 IVA manhours and 5 EVA manhours [32].

3.3 Storage of Propellant

Stationing LH2/LO2 fueled transfer vehicles on Gateway creates the requirement for fuel storage capabilities in support of these vehicles. Since LH2 is stored at 4K and LO2 is stored at 20K, cryogenic storage facilities in space have been the object of much research. Explosion of cryogenic storage facilities is not a concern, as LH2 and LO2 only become dangerous when mixed; an event that can only occur during a possible accident when refueling a spacecraft. The main consideration in cryogenic storage is fuel loss due to evaporation or boiloff.

3.3.1 Cryogenic Storage System

The LH2/LO2 storage tankset recommended by General Dynamics for use on a permanent space station is the center of the refueling system to be housed on Gateway. Figure 3-9 shows a General Dynamics tankset and Table 3-1 lists some of its specifications. Since this storage facility is a passive system, it does not require the development of a long-lived cryogenic refrigerator and can therefore be implemented with present technology. Each tankset is insulated with a highly efficient thick multilayer insulation (MLI). The MLI system for each storage tank within the tankset is about two inches thick. Vapor-cooled shields (VCS) are another important element of this passive long term cryogenic storage facility. A VCS consists of an aluminum shell permeated with flow channels. This shell is located at an optimum distance from the tank wall within the MLI. Hydrogen boiloff vented in zero gravity is routed through the VCS that surround both the LH2 and LO2 storage tanks. Part of the heat incident on the tankset is intercepted by the VCS thus reducing boiloff rates. The thermodynamic coupling between the LH2 and LO2 tanks allows the storage facility performance to be tailored to eliminate LO2 boiloff at the expense of LH2 boiloff. This reduces the complication in storing boiloff since a combination of LO2 and LH2 boiloff would have to be stored separately. Each tankset will also have to have micrometeoroid shielding. Since the most dangerous aspect of the space based refueling depot is the refueling process itself, automation in the refueling process will be required and refueling areas will be as far as possible from crew modules.

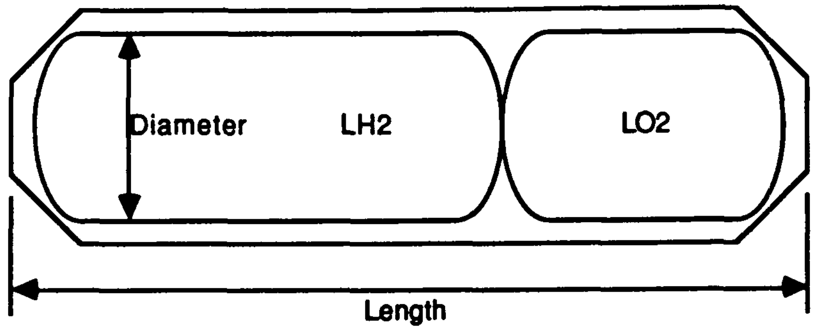


Figure 3-9 Gateway Cryogenic LH2/LO2 Storage Tankset

Table 3-1 Tankset Performance Specifications

Boiloff Management Method	Passive	
Propellant Capacity	45400	kg
Diameter	4.42	m
Dry Weight	12600	kg
MLI Thickness	102	mm
Coupled VCS	Yes	
Hydrogen Loss	143	kg/mo
Oxygen Loss	0	kg/mo
Electrical Energy Use	146	kW/mo
Total Boiloff	< .2%	

3.3.2 Boiloff Management

Hydrogen boiloff collected at Gateway will be stored in spherical high pressure containers. These containers will be vented two miles from Gateway using the OMV. A General Dynamics study revealed that an OMV mission to transport a 4540 kg boiloff storage vessel (carrying 225 kg LH2 boiloff at 20.7 psi) through a two mile altitude change would cost approximately $1.24 million. This is much less expensive than bringing empty storage vessels up from Earth and returning the full ones [32]. Possible uses for boiloff on Gateway were also investigated. Boiloff can be used in the areas of propulsion, life support, and science or technology. Since Gateway will not be involved in any scientific experimentation, the hydrogen boiloff is not useful for scientific purposes. The boiloff requirements for propulsion and life support systems far exceed the expected boiloff rates. The possibility of using boiloff to supplement the cold gas requirements of propulsion or life support exists, but it is dependent on the specific systems utilized. More research will have to be done to determine the feasibility of using boiloff in this manner.

3.3.3 Ice and Electrolysis of LH2/LO2

The presence of an electrolysis unit on Gateway would not eliminate the need for a cryogenic storage facility, but because transporting water(H2O) to Gateway from Earth would be both more economical and safer than transporting LH2 and LO2, use of an electrolysis unit on Gateway to convert ice to LH2 and LO2 was considered. However, electrolysis of LH2/LO2 was rejected due to amount of power required to convert ice to LH2/LO2 at an acceptable rate. This combined with the extremely large mass and volume of the electrolyzer unit made use of electrolysis on Gateway unfeasible with present technology. In order to produce an acceptable amount of of LH2 and LO2 in a set period of time assuming current technology (say 657lbs/hr of LH2/LO2 which will roughly refuel one OTV in 2 weeks of nonstop work) a 222404 lb electrolyzer unit, containing a total of 13489 cubic feet of volume and requiring 987 kW of electric power would have to be installed on Gateway [9]. This would require the entire payload capacity of one HLLV to launch and require far more power than can be generated by the power systems recommended for Gateway. A graph of power required to fill one fuel storage tankset (45400kg of LH2/LO2) versus number of days to fill the tankset is provided in Figure 3-10. This plot shows that the 20 kW Gateway might be able to spare for electrolysis would take years to fill one tankset.

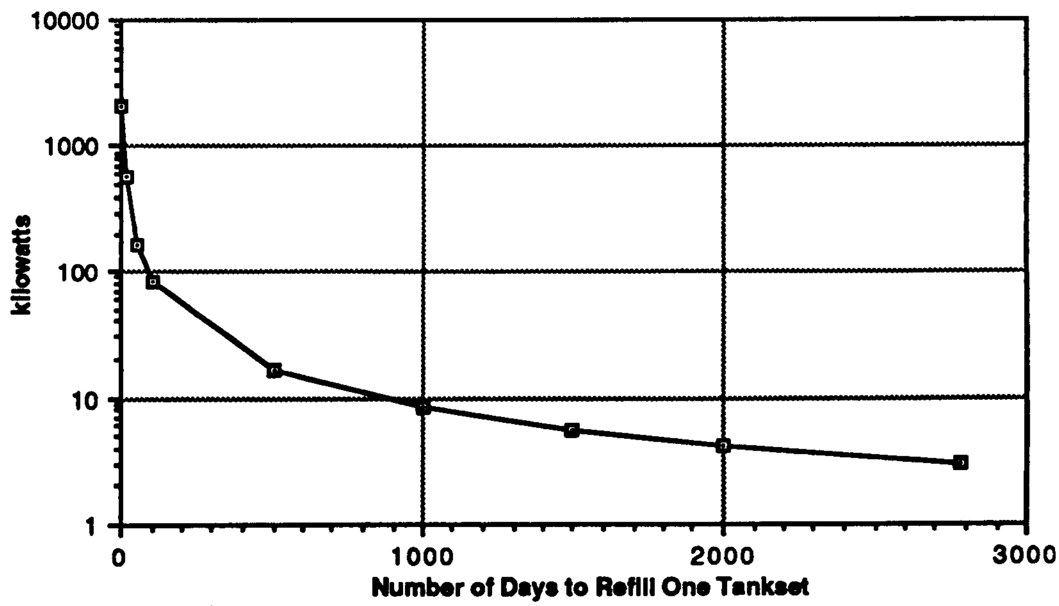


Figure 3.10 Power Requirements for Electrolysis of LH2 and LO2 in Space

3.3.4 Propellant Transfer Techniques

The zero gravity environment requires special pressurization to initiate and maintain fuel flow between tanks. Special systems will be required to create the pressure gradient necessary in refueling vehicles in space. General Dynamics developed a refueling process in 1980. It involves injecting the receiver tank with small charges of propellent to cool the tank to cryogenic temperature. This process also involves vaporization of a small amount of liquid from the storage tank to provide the ullage volume and net positive suction head required for cryogenic pump operation. It is assumed that this or a similar process will be available for use on Gateway.

3.3.5 LO2 and LH2 Transportation from Earth

For a typical fuel resupply mission, an HLLV will launch 90000 kg (about two tanksets) of LH2 and LO2 from Earth. The fuel will be delivered to Gateway in in a light weight expendable storage tank and transferred to the permanent tanksets upon arrival. The OMV (Orbit Maneuvering Vehicle) will intercept the fuel tank approximately two miles from Gateway and ferry it directly to the fuel transfer area. Afterwards the empty storage tanks will be deorbited. Another resupply scenario we considered involved launch of full Gateway tanksets on an HLLV to be clamped onto Gateway in exchange for empty tanksets that would be returned to Earth in the Shuttle payload bay. This option avoids the loss of expendable equipment and avoids the fuel transfer between tanks upon arrival at Gateway. However, it significantly reduces the amount of fuel per launch while increasing the number of Shuttle flights per year to Gateway to return empty tanksets. Possible uses of the empty fuel tanks were also considered in lieu of the deorbit option. Gateway will have no use for the large number of tanks that will be launched to Gateway. Attaching these tanks to Gateway or placing them in an orbit near Gateway until a use for them is found poses other problems. Placing them in orbit would require extra OTV missions and therefore extra OTV maintenance. Attaching them to Gateway would add considerable surface area to the structure and increase atmospheric drag. Finally, purging the remnants of LH2 and LO2 left in these tanks to clear them for other uses would be a costly and possibly dangerous task. Until a use for the fuel tanks delivered to Gateway is found, the deorbit scenario will be the simplest and most economical approach.

3.3.6 Payload Management at Gateway

Payloads delivered to Gateway intended either to continue to the Moon or for support of Gateway will go through a similar procedure. The HLLV will deliver the payload within two miles of Gateway where the OMV will intercept it and ferry it to the hangar area. Payloads that will be transferred to the Moon will not be unloaded at Gateway, but will either be attached directly to the OTV stack for transfer to the Moon or be put in storage until ready to be transferred. Gateway resupply payloads will be brought directly to the hangar facility and unloaded by either teleoperation or EVA. The amount of non-usable containers delivered to Gateway will be kept to a minimum. All waste materials will be returned to Earth in the Shuttle payload bay.

3.4 Crew Manhour Study

Gateway's crew is sized by determining how many man-hours must be spent on various tasks. Gateway assembly, OTV docking and maintenance, cargo transfer, and general housekeeping times are considered in this process. The total number of man-hours for both Intra Vehicular and Extra Vehicular Activities (IVA and EVA, respectively) are determined and compared to constraints placed on the amount of time a crew member may spend working.

3.4.1 Crew Constraints

There are limits to the amount of work crew members may perform. For Space Station, each crew member is expected to work 10 hours/day, 6 days/week [29]. Assuming 52 weeks in a year, there are 3120 available work hours per crew member per year.

Extra-Vehicular Activity (EVA) imposes further constraints on crew scheduling. Each EVA requires three crew members: two outside, performing the actual EVA, and one inside, monitoring the process. The monitor's hours for this activity are counted at half-time since other simple tasks may be accomplished simultaneously. The maximum length of a single EVA is six hours and crew members are restricted to no more than three EVA's per week [29].

In addition to straight EVA time, a certain amount of EVA preparation time must be accounted for when EVA hours are tallied. Suiting-up procedures must be included, as well as EVA equipment servicing. For current technology equipment, the preparation/maintenance time amounts to approximately 0.68 IVA hours for each hour of EVA [19].

3.4.2 Process Times

Gateway assembly time depends heavily upon the structure of the station. A greater crew complement would be required to construct a larger structure piece by piece. The construction phase would involve much EVA time.

OTV and OMV docking is monitored by the crew. Cargo transfer and OTV maintenance are also crew-intensive activities. A General Dynamics study of OTV maintenance and handling produced rendezvous and berthing times of 7.5 man-hours (mhs) for each vehicle docked, and launch times of 13. Payload integration and refueling were determined to be 13.5 mhs, assuming a moderate level of automation [32].

Since much uncertainty exists in OTV maintenance and processing times, more conservative time estimates were used in the determination of the necessary crew complement for Gateway. A time of 150 mhs was used for docking and maintenance, while 100 mhs was used as the load/launch time. Incoming cargo transfer and stowage times were estimated at 150 mhs for the shuttle and 300 mhs for an HLLV. 150 mhs was used as an estimate for OMV maintenance/refueling.

In addition to the time necessary to perform mission-related tasks, basic everyday items must also be taken into account. The accepted lump sum for general housekeeping chores is 40% above hours required for mission-related tasks [4].

A Gateway crew complement of four was deemed necessary for the first fifteen years of Lunar Base buildup. Table 3-2 shows the calculations determining this number.

Table 3-2 Gateway Crew Times

OTV docking, maintenance	150	mhs/mission (x6 OTV flights/year) (x2 OTV's/flight)
OTV load, launch	100	mhs/mission (x6 OTV flights/year) (x2 OTV's/flight)
Unload Shuttle	150	mhs/mission (x10 flights/year)
Unload HLLV	300	mhs/mission (x4 flights/year)
Refurbish OMV	150	mhs/mission (x8 refurbishments/year)
TOTAL	6900	mhs/year
(Assume 10% EVA time)	+ 7 %	
	7383	mhs/year
(Housekeeping)	+ 40 %	
GRAND TOTAL	**10,336**	**mhs/year needed for Gateway operation**

A crew of four provides 12,480 available hours, leaving some extra as a safety factor in the event more EVA is required to take care of unforeseen problems.

3.4.3 Automation

Many of the crew-intensive tasks discussed lend themselves to automation. Gateway assembly, OTV docking, cargo transfer and routine maintenance can all be automated to some extent to free the crew for other tasks.

To minimize EVA activity, a deployable truss structure is desirable for Gateway's base. Gateway construction could easily require a larger crew complement than the fully operational station. A deployable truss would alleviate this somewhat.

Automation may also be helpful in OTV-related activities. A reliable, fully-automated docking system should be operational by the time Gateway is in place. Furthermore, OTV refueling should be automated for safety reasons mentioned earlier.

This study assumes heavy use of teleoperation systems, in which an operator in a shirt-sleeve environment manually controls equipment that is capable of sensing, manipulation and/or mobility. This type of system cuts the amount of EVA time necessary for OTV maintenance and cargo transfer [10]. Ideally, a facility such as Gateway could be totally automated, but current designs for OTV's, OMV's, and payload handling techniques are man-intensive. As automation technology matures, Gateway could be rotated out of its permanently man-tended status and evolve into a fully automated facility.

3.5 Summary of Sizing Process

In order to determine Gateway's structural requirements, several studies were accomplished. First of all, a traffic model was determined. Information was gathered concerning OTV and crew requirements and abilities, and fuel storage techniques. These things produced specific requirements for Gateway's structure and were used to define Gateway's IOC and subsequent yearly development.

4.0 STRUCTURE SELECTION

The final step of Project Gateway is to determine a suitable configuration and power system for the Gateway station. A configuration will be recommended merely as a way of presenting the requirements of Gateway, such as the number of OTV's, the number of docking ports, the amount of fuel storage space needed, and the number of crew modules, for better understanding. The final configuration is also needed to determine the total mass that will be put into orbit. This is needed for cost purposes, for timeline purposes, and for sizing purposes in determining the orbit.

It must be emphasized that the main objective of Project Gateway is to determine the requirements for the space-based transportation node. The configuration that will be recommended is not a detailed configuration; it is a general description that will be used for visualization of the activities occurring on Gateway.

The method of approach to the structural design problem and to the power system design problem is shown in the flow chart in Figure 4.1. First, design criteria is defined while information on possible designs is gathered. Next, a decision table is used to determine which possible design best meets the design criteria, and from that a final design is recommended.

The configuration that was selected is the Delta Truss Structure, and the selected power system is a combination of solar photovoltaic and solar dynamic systems. The following sections outline the reasons for these selections.

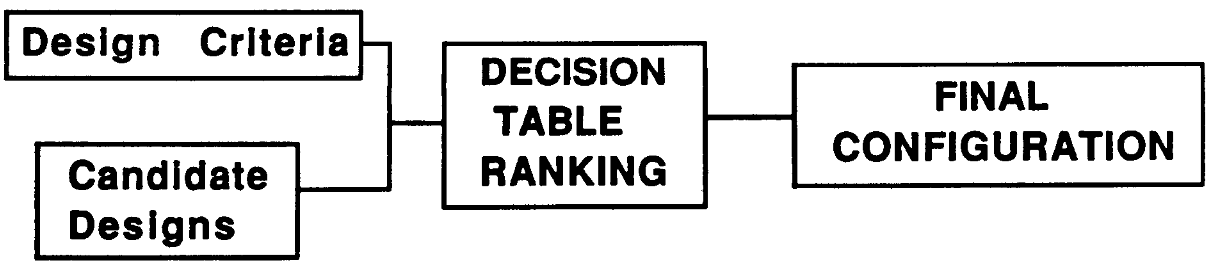


Figure 4-1 Structure Design Process Flow Chart

4.1 Structural Design Criteria

The configuration of Gateway will consist of four basic parts: 1) habitation, 2) service, assembly, storage, 3) utilities, 4) interconnection.

The basic design requirements for the Gateway configuration come from the traffic model output, the OTV study, the manhour study, and general space structure requirements. Each candidate design must first meet the specific requirements found in the traffic model output, the OTV study, and the manhour study. These designs are then ranked according to how well each meets the general space structure requirements.

The flow chart in Figure 4-2 outlines the requirements found in the lunar base scenario, OTV, and manhour studies. The final objective of these studies is to find the number of docking ports, amount of fuel/supply storage facilities, amount of OTV hangar space, and number of habitation and crew modules for the Gateway final configuration. An explanation of how this criteria is obtained follows in the next three sections.

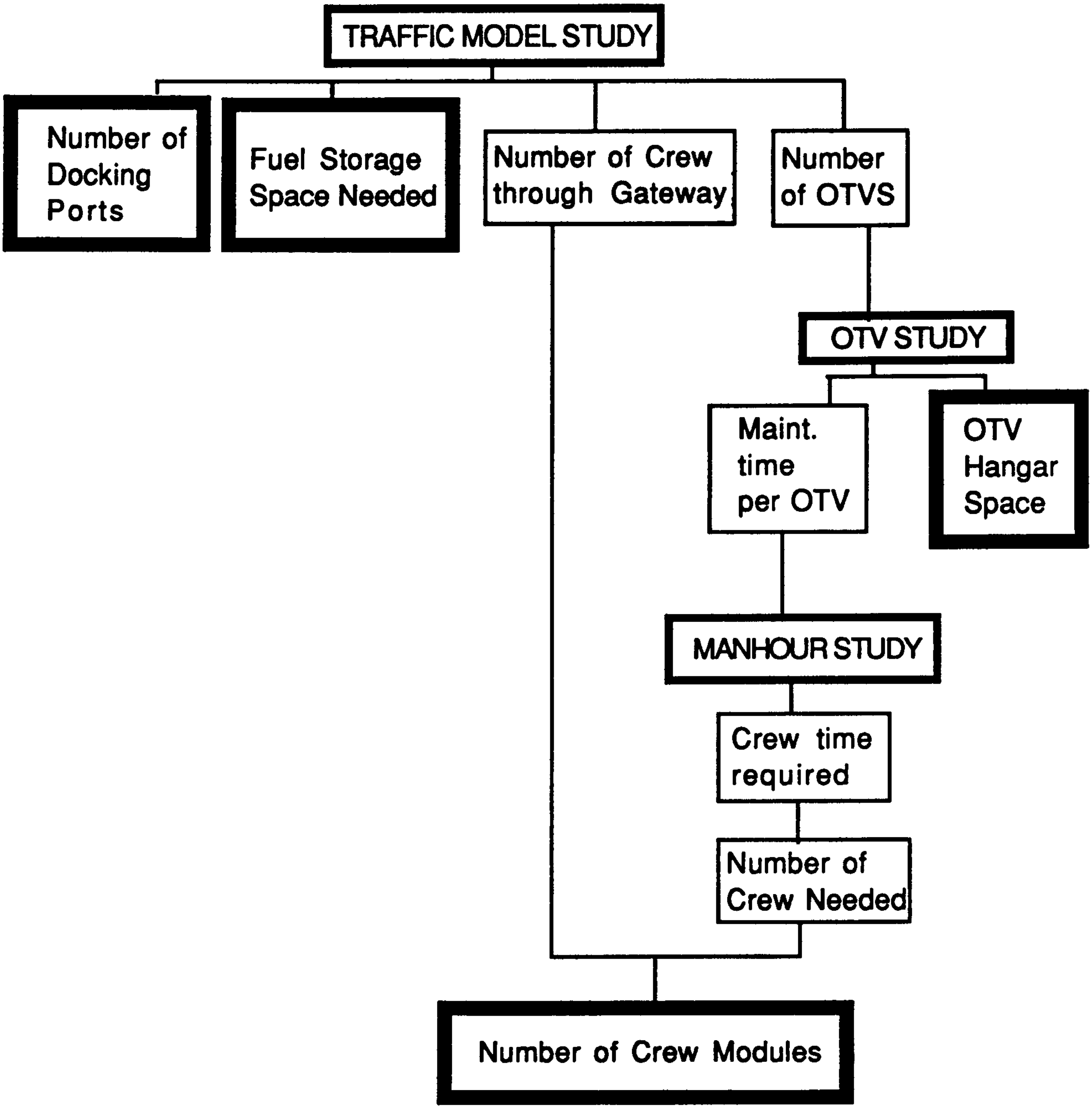


Figure 4-2 Development of Design Criteria Flow Chart

4.1.1 Lunar Base Scenario Outputs

The traffic model output gives the following information:

1. 4 HLLV flights/year for years 1-11.
   5 HLLV flights/year for years 12-15.

6 HLLV flights/year for years 16+.

2. 3 shuttle flights/year for year 5.
   4 shuttle flights/year for year 6.
   5 shuttle flights/year for years 7-14.
   Shuttle flights increase each year for years 15+.
3. 4 Lunar Base crew members come through Gateway on each shuttle flight.
4. 1 OTV flight/year for year 2.
   6 OTV flights/year for years 3-14.
   OTV flights increase each year for years 15+.
5. Maximum fuel stored at Gateway at any one time requires 3 fuel storage tanks.

4.1.2 OTV Study Output

The OTV study output gives the following information:

1. Each OTV weights 87,000 pounds in a 1-g environment.
2. The hangar facility must accommodate 2 standard OTV's and a 50 ft. long
   payload or OMV. Suggested dimensions are 25m x 30m x 45 m.
3. Fuel storage tank characteristics:
   45,400 kg capacity, 6:1 O2/H2 ratio
   Length 13.3 m, Diameter 4.42 m
   Dry mass 12600 kg
   100 manhours turnaround time per OTV.

4.1.3 Manhour Study

A four member crew is adequate for early Gateway operation. Three crew members are necessary to perform an EVA. The four man crew can easily perform OTV maintenance and have time available for other station tasks. The Space Station common modules are used to house this crew. Thus, two habitation modules and one logistics/work module are needed. One habitation module will be outfitted for the full complement of eight to allow for transient crew through Gateway. The other habitation module will be used for recreation and will include the health maintenance facilities.

4.1.4 General Space Structure Requirements

The candidate designs that meet the design criteria above are ranked in a decision table according to general space structure requirements. Specifically, the mass of the structure should be minimized and the stiffness should be maximized (because of the frequent docking at Gateway.) Also, the structure must be expandable for future growth. The ease of launch and assembly of the structure should be maximized. Finally, the structure must account for some type of micrometeoroid and radiation protection.

4.2 Candidate Structures

The four candidate designs are all space station configurations that have already been defined. They are the Power Tower, Dual Keel, Critical Evaluation Task Force (CETF) Model, and Delta Truss. The Boeing Large Space Structure Design is also considered as an addition for the Power Tower, Dual Keel, and CETF models. These five are described in each of the following sections. Each section contains a description of the basic configuration, a measure of stiffness and weight of the structure, and advantages and disadvantages of each. Natural frequency is used as a measure of stiffness. A high natural frequency corresponds to a stiff structure. The lowest natural frequency of each structure was used for comparison.

4.2.1 Power Tower

The Power Tower configuration is shown in Figure 4-3. It consists mainly of a long beam truss for interconnection between the solar array panels at one end and the crew modules and shuttle docking port at the other.

The lowest natural frequency of the Power Tower configuration is approximately 0.1 Hz. The total weight of the structure is around 450,000 lbs [2].

An advantage of the Power Tower is that it affords good viewing to all payloads and provides good clearances for rendezvous and docking. However, it has low stiffness as compared to other configurations. It would also require additional hangar space for Gateway activities, and the beam truss provides little support for a hangar facility. Finally, the Power Tower is not suited very well for expansion or for storage .

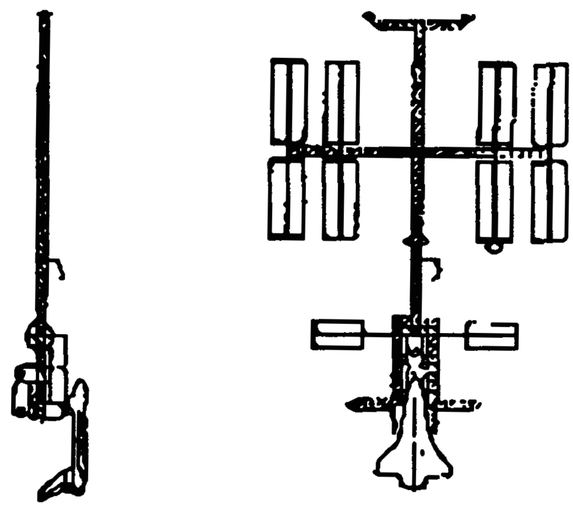


Figure 4-3 Power Tower Configuration

4.2.2 Dual Keel

The Dual Keel configuration is shown in Figure 4-4. The truss structure consists of a long beam with a dual keel, as shown. The crew modules and shuttle docking port are located in the center of the structure.

The lowest natural frequency of the Dual Keel configuration is 0.15 Hz. The total weight of the structure is approximately 465,000 lbs [2].

The Dual Keel also provides good clearances for rendezvous and docking, and it is stiffer than the Power Tower structure. However, it also requires additional hangar space for Gateway activities and it has limited storage facilities.

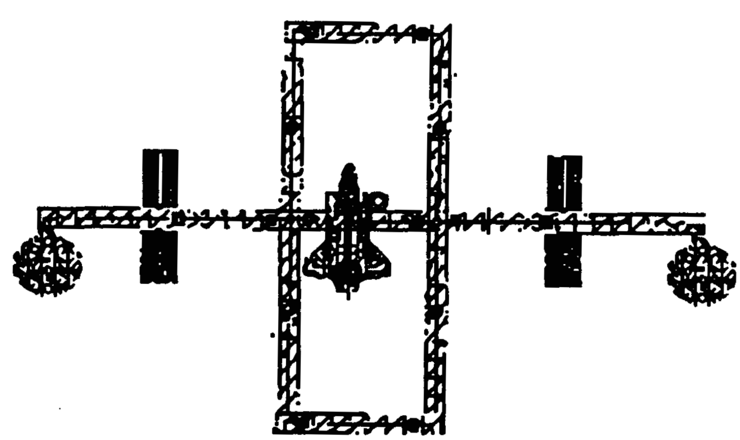


Figure 4-4 Dual Keel Configuration

4.2.3 CETF Model

The Critical Evaluation Task Force (CETF) Model is basically a stripped-down version of the Dual Keel configuration. It is shown in Figure 4-5 and consists of a long beam truss only. The crew modules and shuttle docking port are located in the center of the beam with solar arrays and radiators at each end.

The lowest natural frequency of the CETF Model is approximately 0.1 Hz. Its total weight around 395,400 lb [2].

The CETF Model also provides good clearances for rendezvous and docking and affords good viewing to all payloads. However, it has low relative stiffness, little support for the necessary extra hangar facility, and limited storage space.

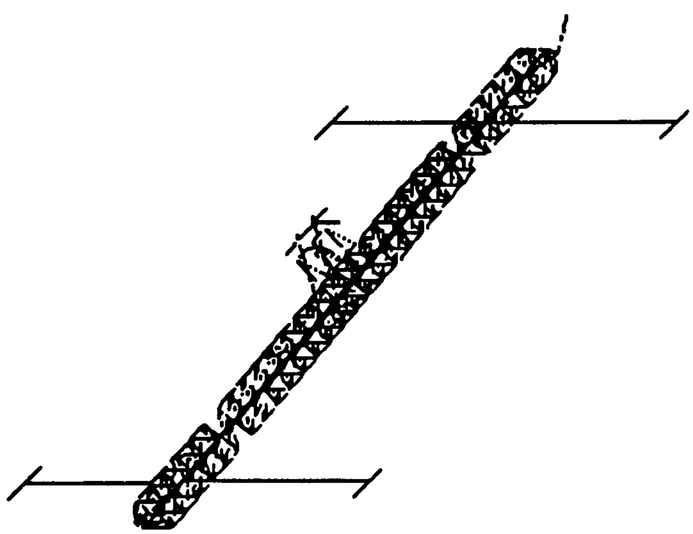


Figure 4-5 CETF Configuration

4.2.4 Boeing Large Space Structure Design

The Boeing Large Space Structure (LSS) Construction/Storage/Hangar Facility is shown in Figure 4-6. It is a lightweight protective hangar that can be added to an existing space station design. It consists of a deployable truss platform attached to a transfer tunnel located at a docking port on a Space Station module.

The lowest natural frequency of the Boeing LSS Design is 9.5 Hz. This is higher than the primary frequencies of any of the existing space station designs, so the additional structure will not pose any significant concerns for the existing control system. The weight of the structure is 1880 kg, and it adds at most a 2.6% increase in area for the entire structure [5].

Compartments can be installed within the truss members to provide storage for small items. Also, loads induced by disturbances such as docking are distributed to many attachment points. The structure would be an adequate hangar addition, if needed.

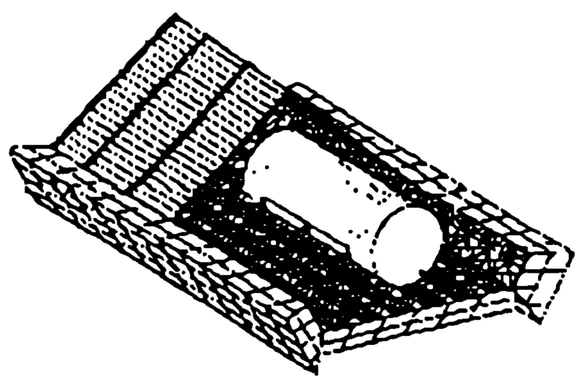


Figure 4-6 Boeing LSS Construction/Storage/Hanger Facility

4.2.5 Delta Truss Structure

The Delta Truss Structure is shown in Figure 4-7. It consists of three simultaneously deployed planer trusses joined at their ends to form an equilateral triangle cross-section. The crew modules are arranged in a race-track configuration with the shuttle docking port located at one apex of the structure.

The lowest natural frequency of the Delta Truss Structure is 3 Hz [23]. The actual weight of the structure is approximately 430,000 lbs.

The advantages of the Delta Truss Structure are numerous. The trusses are self-deploying to minimize crew involvement in set-up, and the total structure for initial operation can be in place after only one shuttle flight. The truss also forms a 'pegboard' surface, which provides large attachable surfaces for storage. The structure is much stiffer than the other space station configurations. This is an advantage not only for docking purposes, but also for reboost and station control due to payload placement. The large enclosed area offers an area for astronauts to perform vehicle maintenance. An astronaut who accidentally "falls off" the structure is likely to remain in the enclosed area and not float dangerously far from safety. Also, solar arrays can be rigidly attached to the truss structure, thus eliminating the need for large rotary joints and providing 'shade', or a relatively constant thermal environment, for the payloads, assuming that the payloads are stored inside the hangar facility provided by the triangular truss structure. However, attaching solar panels to the face of the structure places a constraint on the attitude of the station, in that the solar panels (one side of the structure) must always face the Sun.

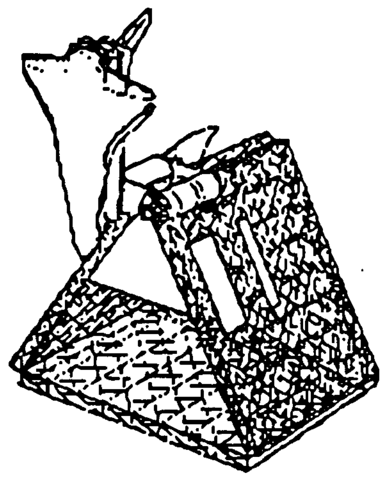


Figure 4-7 Delta Truss Configuration

4.2.6 Decision Table Ranking

Table 4.1 shows the decision table ranking of the four candidate designs. The design criteria have been weighted using the method of pairs. The designs were ranked on a scale of 1 to 3, with higher numbers best. The results clearly show that the Delta Truss is best suited to Gateway's needs. Thus, the suggested final configuration will consist of Gateway components arranged on the Delta Truss structure.

Table 4-1 Configuration Decision Table

	Wt.	Power Tower	Dual Keel	CETF	Delta Truss
Mass	1	2	2	1	2
Stiffness	5	5	10	5	15
Expandability	4	4	4	12	12
Ease of Launch and Assembly	3	3	3	6	9
Available Hangar Space	2	2	2	2	6
TOTAL		16	21	26	44

4.3 Power System Section

To determine a power system suited to the needs of Gateway, the approximate power requirements of Gateway must be determined. Candidate systems, which produce the power required, can then be ranked according to how well each meets general space power system requirements. In the following sections, the power requirements of Gateway and general space power systems are defined.

4.3.1 Power Requirements

The estimated power requirements for Gateway is 200 kW. The main subsystems using this power are the guidance and control system, ECLSS, EVA, thermal control, crew accommodations and health maintenance, and Gateway activities requiring the RMS, MRS, or other robotics/automation [7]. The cryogenic fuel storage power requirements were found to be very small compared to these other subsystem usages.

4.3.2 General Space Power Requirements

The candidate power systems are ranked according to how well each meets the general space power system requirements. These include minimizing mass and size, and thus drag. The cost to build, launch, and operate should also be minimized. However, safety, reliability, and efficiency should be maximized. The power system should also integrate well with the vehicle. An example of good vehicle integration is the solar panels attaching rigidly to the Delta Truss Structure. Also, the power system should interact well with the mission. The same example applies again, in that the solar panels place an additional constraint on the Gateway mission. They require a solar oriented flight mode for power system operation. Finally, operating lifetime should be maximized, operating temperatures should be low enough for the materials used, and an adequate waste heat rejection system should be provided.

4.3.3 Candidate Power Systems

Solar photovoltaic, solar dynamic, and nuclear power systems were considered for use on Gateway. Chemical fuel cells are suggested as a back-up power system.

Solar Photovoltaic

The solar photovoltaic (PV) power system consists of solar arrays, power storage batteries, PV electronics, and thermal control and heat rejection for energy storage and power management and distribution (PMAD) losses. An example of a Silicon Photovoltaic Power System provides 75 kW of electricity, with specific power of 40 W/kg. It has a ten year lifetime and a 55% efficiency. Each solar array weighs 10,772 lbs and requires 19,200 square feet of space [7].

Solar Dynamic

The solar dynamic (SD) power system uses a mirror to collect and concentrate the Sun's energy on a heat receiver. A heat engine is then used to extract energy from the receiver and convert it to mechanical energy to drive an electrical alternator. The SD power system currently designed for the Space Station has eight units producing 37.5 kW of electricity each. Each unit weighs 3410 kg and has an 18 m diameter mirror/radiator [7].

Nuclear

Nuclear power has several advantages over solar power. For example, at large power levels, it is possible to realize specific energy density levels that cannot be attained by solar power. Nuclear systems are also smaller, have no bulky solar panels, and are more maneuverable. However, nuclear systems require large minimum weights, and there are political problems associated with putting a nuclear power system in Earth orbit [1] to support this crew.

An example of a nuclear power system is the SP-100 Space Reactor Power System, a fast spectrum-pin type geometry, lithium cooled system. It produces 10-1000 kW and weighs 1000-20,000 kg. It has a 10 year lifetime, 95% reliability, and 0.05% efficiency. Operating temperatures range from 1350 degrees Kelvin at the outlet to 1650 degrees Kelvin for the fuel [21].

Chemical Fuel Cells

For long space missions, the primary source of energy cannot be chemical because the weights of fuel and oxidant would become prohibitive. Chemical fuel cells can be used, however, as emergency and peak power sources in connection with solar or nuclear systems. Chemical fuel cells have many advantages, such as high efficiency, silent operation, no moving parts, no power consumption while idling, no noxious exhaust, modular construction, and high peak load capacity [27].

One chemical fuel cell module can produce 20 kW, weighs 1262 lbs, and requires 75 cubic feet of space. The recommended fuel and oxidant are hydrogen and oxygen, respectively.

4.3.4 Decision Table

Table 4.2 shows the decision table ranking of the candidate power systems. The design criteria have been weighted using the method of pairs. Since the PV and SD power systems had approximately the same ranking, a combination of the two will be used on Gateway. The solar arrays will be used to produce 75 kW. Eight SD units will be used to produce 300 kW. The extra power generated by this system will be stored for use when Gateway is not in direct sunlight.

Table 4-2 Power System Decision Table

	Wt.	Solar Photovoltaic	Solar Dynamic	Nuclear
Mass	1	2	1	3
Size/Drag	2	2	4	6
Reliability	6	12	12	18
Safety	7	21	21	7
Efficiency	2	4	4	2
Vehicle Integration	3	9	6	3
Mission Interaction	3	6	6	3
Lifetime	3	9	9	6
TOTAL		65	63	48

4.4 Structures Summary

Based on the results of studies of docking activity and OTV and OMV maintenance requirements, and taking into account such factors as propellant storage hazards, orbital debris generation, and the future goals of the American space program, UTMD strongly discourages the use of the NASA Space Station or any other research-oriented facility as a transportation hub. A separate structure should be constructed to meet the transportation needs of a successful space program.

The Delta Truss Structure is recommended for use as the framework for Gateway. The structure's stiffness provides excellent support for docking and reboosting loads. In addition, a protective sheet can be placed inside the truss to sheild vehicles, modules, and crew from micrometeoroids and possibly radiation. This sheet may also serve to contain any debris which is generated inside the structure during normal operations. This is certainly a long term advantage of a Delta Truss over a simple platform. The recommended power system is a combination of the solar photovoltaic and solar dynamic systems.

5.0 FINAL SELECTION

This section outlines a suggested configuration for Gateway and estimated launch schedule. This configuration assumes the baseline JSC Lunar base scenario. Figure 5-1 shows a recommended arrangement of components on the Delta Truss structure.

5.1 Gateway Components

Gateway will consist of the following components, based on the previously stated conditions:

Table 5-1 Gateway Mass

Truss structure	9000 lb.	[6]
Habitation module (1)	84000	[9]
Logistics/work module (1)	42000	[9]
Safe Haven	8000	[9]
Cupola (1)	1600	[9]
Node (6)	48000 (total)	[9]
Airlock (2)	10000 (total)	[9]
Docking port (3)	3300 (total)	[9]
EVA equipment	4300	[23]
Radiation/micro-meteoroid protection	8000	[23]
Tele-robotics system	2000	[9]
Attitude/altitude control	31000	[9]
Power system	70800	[7]
Remote manipulator system (2)	10000 (total)	[9]
Mobile remote servicer (2)	4000 (total)	[9]
Fuel storage tanks (3)	83000 (total)	[32]
OMV (1)	10700	[9]
OTV (2)	174000 (total)	[32]
Total	603700 lb.	

The OTV masses are not included when figuring the total launch mass for Gateway, since the Lunar Base operation includes them in its launch mass.

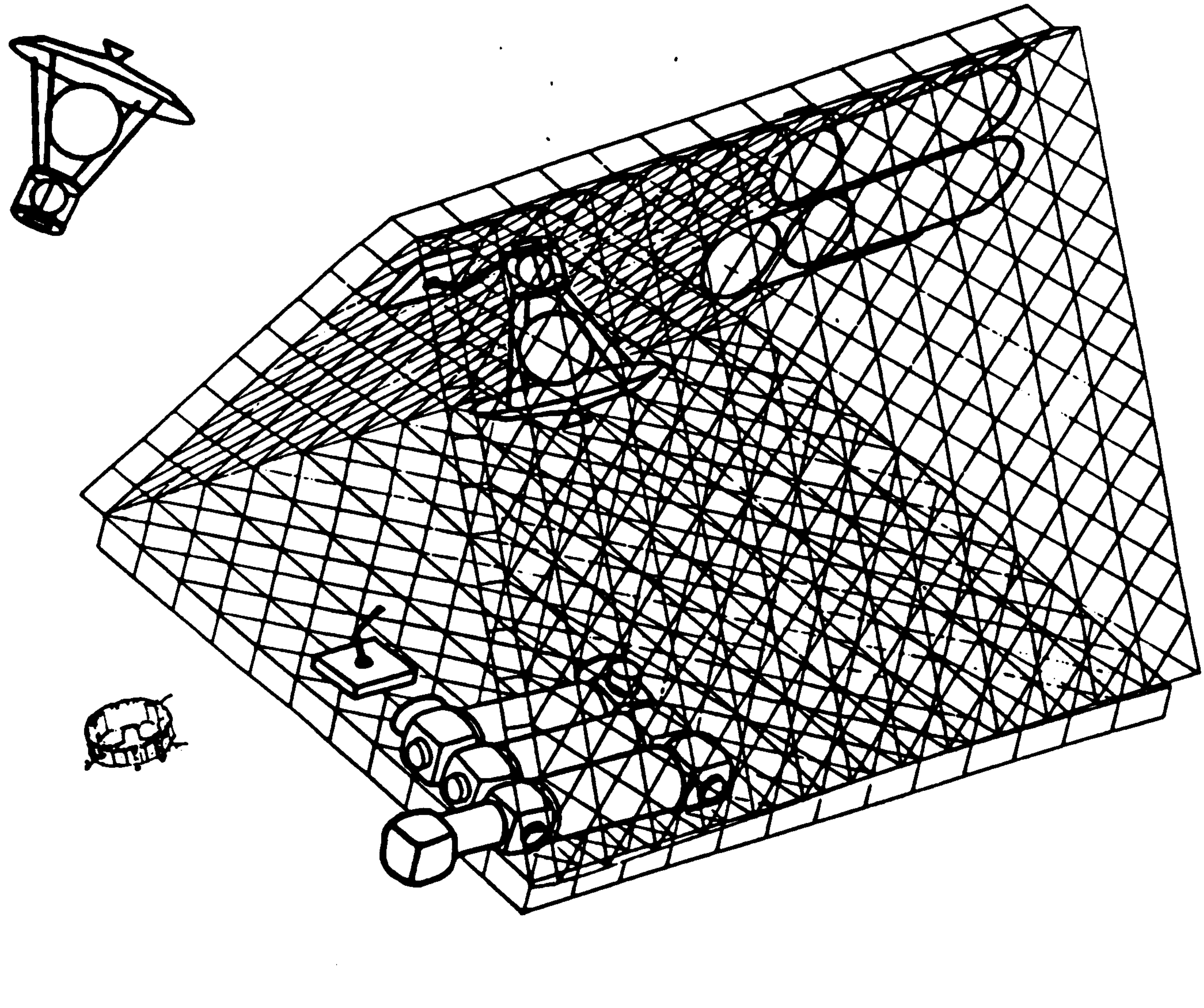
5.2 Launch and Assembly

Gateway may attain IOC after five launches. The first four are shuttle flights and the last an HLLV flight. The Gateway will be manned after the fourth launch.

5.3 Crew Activity

A permanent crew of four is recommended for Gateway. Based on the general time line, Gateway activities should keep a permanent crew of four busy at all times.

Figure 5-1 Recommended Delta Truss Structure Configuration



6.0 RESULTS

The primary conclusion reached by UTMD was that a separate facility from the Space Station should be constructed to serve as a transportation node. The activity level associated with a transportation node will be too great to incorporate into the delicate microgravity enviornment of a research facility. Bumps from docking and large mass shifts due to payload transfers, along with exhaust plumes from the vehicles impinging on sensitive instruments will interfere with the research enviornment. A second space structure such as Gateway is needed to free our national research laboratory from the burden of being a "busy intersection", and to provide redundancy for America's quest to maintain a permanent presence in space.

UTMD has selected the Delta Truss structure as the best candidate to support the traffic associated with the proposed Lunar base and future interplanetary missions. The Delta Truss provides an excellent framework for the components which UTMD determined will be needed to support Lunar base buildup and operation. During the first ten years of Lunar base operations, the structure must accommodate one orbital transfer vehicle, one orbital maneuvering vehicle, 110 MT of liquid hydrogen/liquid oxygen propellant storage, and docking facilities for the Space Shuttle and HLLV. Equipment to transfer payload from the launch vehicles to the OTV's is also needed. UTMD determined from a study of crew workloads that the facility should house a permanent crew of four vehicle maintenance and payload integration specialists. Using data generated from the UTMD Orbit Determination Program, UTMD selected a circular orbit between 240 and 270 nautical miles, with an inclination of 28.5 degrees. Kennedy Space Center was selected as the launch facility; however, UTMD recommended the construction of a launch facility in Hawaii to economize the long term operation of a Lunar base and aggressive interplanetary exploration program. The transportation hub has been named **"Gateway"** by the UTMD design team to stress its role in providing access to the Moon and beyond.

7.0 MANAGEMENT OVERVIEW

UTMD was composed of eight senior aerospace engineering students. At the beginning of the Spring 1988 semester, a project manager was selected to serve as the overall leader of the project. The remaining group members split into two branches of the company, depending upon their individual areas of interest. Those who were more inclined toward structures and operations formed the Operations Team. Members who were more skilled in orbital mechanics composed the Orbit Determination Team. Two team leaders were selected to head the Operations and Orbit Determination Teams. The company structure is shown in Fig 7-1.

7.1 Final Cost Status

Fig 7-2 was updated each week to monitor the number of hours spent per week by the employees. The large drop in week 9 was due to the one-week spring break vacation. Large peaks occur just before reports or presentations are scheduled. Fig 7-3 is a record of the cumulative manhours spent by the entire design group. The straight line represents the maximum allowable hours to be spent on the project.

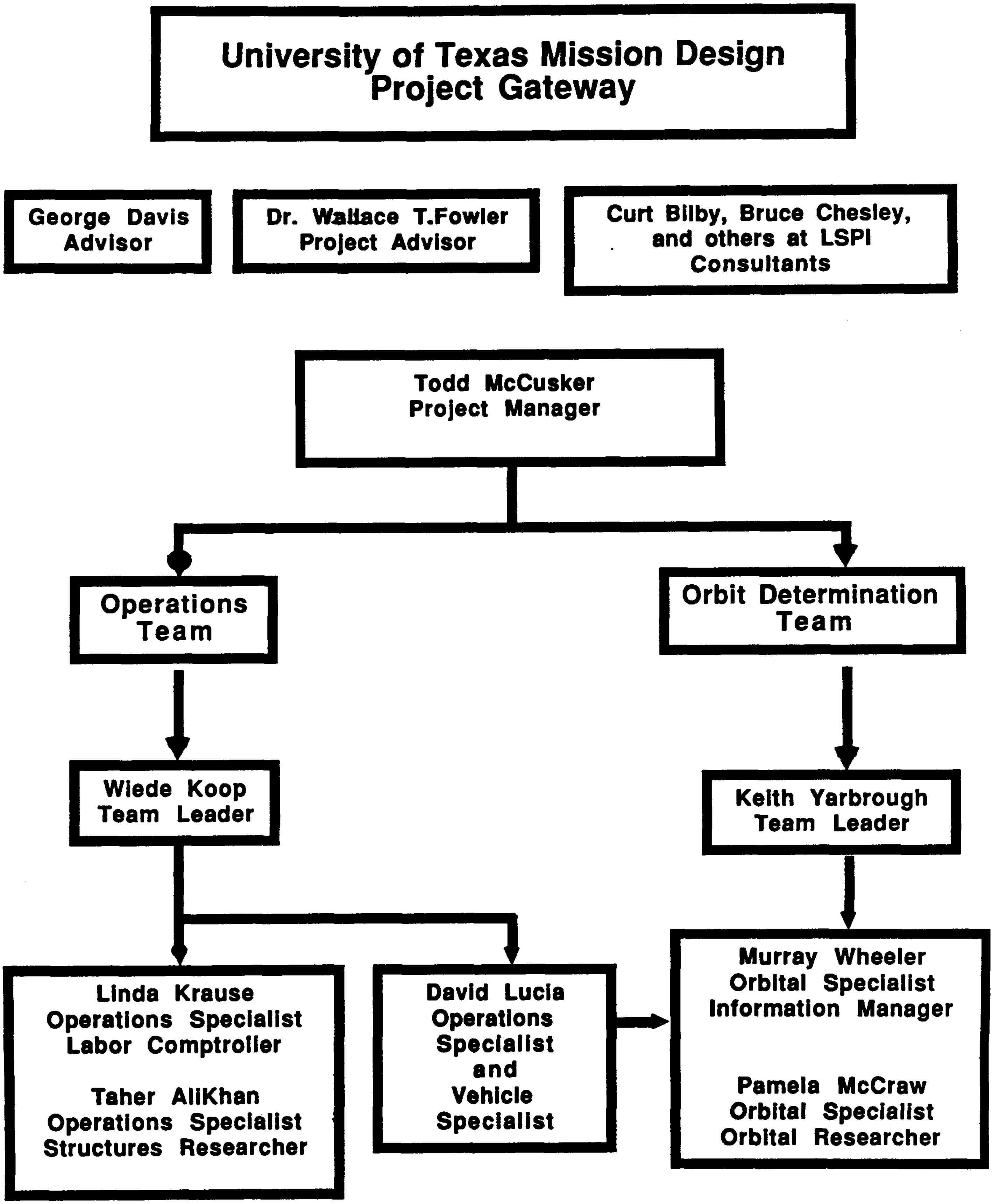


Figure 7.1: UTMD Company Structure

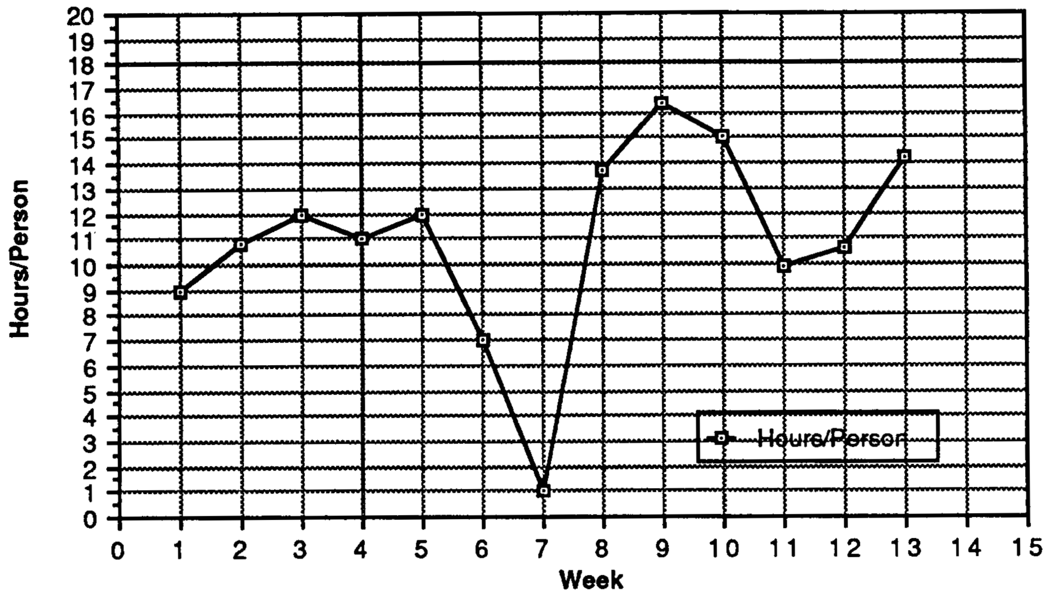


Figure 7-2 Average Hours per Person per week

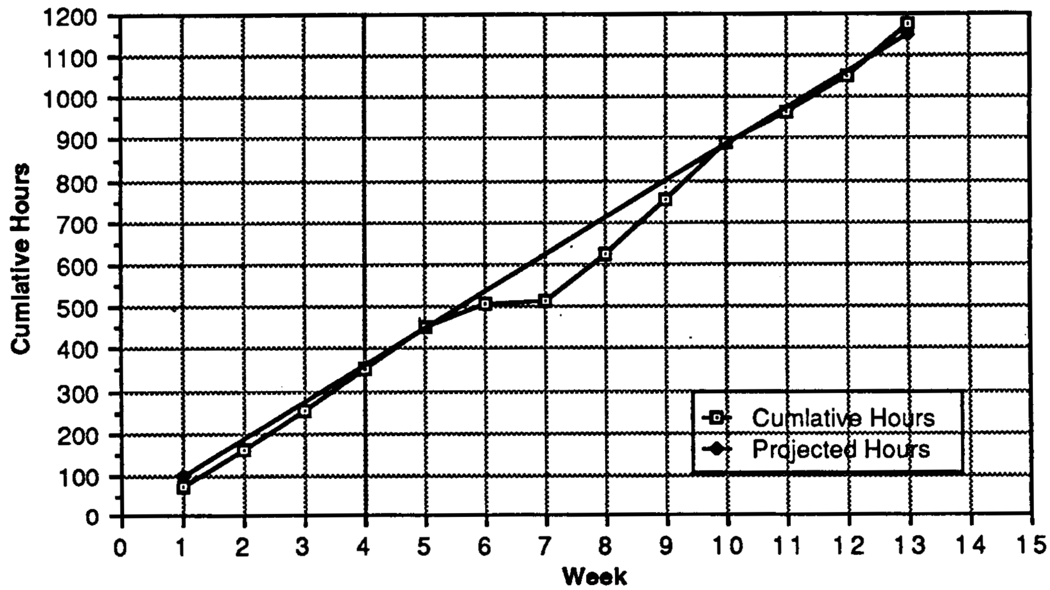


Figure 7-3 Projected and Actual Cumulative Manhours

Income:

The information manager at UTMD provided his computer expertise to another University of Texas Design Team, The Mars Company (MARCO). MARCO agreed to pay UTMD according to the following contract:

1 information manager for 15 hours of consulting @ $75 = $1125 income

The Projected personnel cost for this project was $25,030. The actual personnel costs are presented below:

Actual Personnel Costs

1	Project Manager	@ $25/hr	*	191hrs	$	4775
2	Technical Director	@ $22/hr	*	295	$	6490
5	Engineers	@ $15/hr	*	679	$	10185
	Reports	@ $06/hr	*	307	$	1842
	Consultants	@ $75/hr	*	20	$	1500
	Less Marco payment				$	-1125
Total Actual Personnel Cost					**$**	**23667**

The actual personnel cost fell $1363 below the expected personnel cost.

The anticipated hardware costs totalled $2720. These costs were based on purchased equipment. A few costs in addition to the anticipated costs were:

Repair 1 Magic 60 Megabyte Hard Drive	$	400
Computer time overshoot	$	5000
(anticipated computer costs)	$	2720
Total Actual Hardware Cost	**$**	**8120**

The hardware costs were underestimated by $5400. This was due to a change in design direction. Originally, UTMD sought to place Gateway in a high enough orbit to neglect atmospheric drag. However, the large surface area of the selected Delta Truss structure along with diminishing Shuttle performance with altitude caused atmospheric drag to become a major concern. To solve the problem of a 90-day satellite lifetime, many integrations of the motion must be performed. The orbit determination program was run approximately 20 times, taking anywhere from 2 to 4 hours to run on the Dual Cyber mainframe. The long run times are encountered when using the Runge-Kutta integrator.

Anticipated Total Cost of Project	**$**	**27750**
Actual Total Cost of Project	**$**	**31787**
Overshoot	**$**	**4037 (14.5%)**

Week 13: April 31, 1988 - May 6, 1988

Name	Group Meetings	Engr.	Admin. Funct.	Sec. Duties	Reports	Other	*Weekly Totals per Person*
Alikhan	3.0	3.0			9.0		**15.0**
Koop	2.0				6.0		**8.0**
Krause	2.0				10.0		**12.0**
Lucia	3.0		3.0				**6.0**
McCraw	2.0	16.0					**18.0**
McCusker	2.0	5.0	2.0		18.0		**27.0**
Wheeler	3.0			1.0	15.0		**19.0**
Yarbrough	2.0	16.0					**18.0**
Totals	**19.0**	**40.0**	**5.0**	**1.0**	**58.0**	**0.0**	**123.0**

Semester Summary
Do Not Enter Data Here

Name	Group Meetings	Engr.	Admin. Funct.	Sec. Duties	Reports	Other	*Weekly Totals per Person*
Alikhan	45.0	59.0	0.0	0.0	30.0	0.0	**134.0**
Koop	46.0	27.0	10.0	5.0	39.0	0.0	**127.0**
Krause	36.0	48.0	5.0	6.0	26.0	4.0	**125.0**
Lucia	41.0	38.0	9.0	2.0	15.0	10.0	**115.0**
McCraw	34.0	72.0	0.0	0.0	25.0	0.0	**131.0**
McCusker	40.0	41.0	39.0	2.0	64.0	5.0	**191.0**
Wheeler	45.0	43.0	10.0	14.0	62.0	0.0	**174.0**
Yarbrough	39.0	72.0	8.0	3.0	46.0	0.0	**168.0**
Totals	**326.0**	**400.0**	**81.0**	**32.0**	**307.0**	**19.0**	**1165.0**

56.5

8.0 PROJECT EVALUATION

This section of the report contains a breakdown of the limitations of the analysis done by UTMD.

8.1 Traffic Modelling

Since Gateway's configuration depends heavily on storage and manpower requirements, defining a projected traffic model for Lunar Base operations and support is an essential requirement. Modelling the expected traffic proved difficult since the actual Lunar Base scenario has yet to be defined. The feasibility of LOX production will also severely impact the traffic model. For the purpose of having a rough order of magnitude, the LSPI Lunar Base model software was used to model the traffic. However, the software also was limiting. For example, in order to mirror the Eagle report as close as possible, some modifications to the software were needed. In addition, a problem had occurred when selecting the appropriate OTV and LM for the transportation fleet. The software only considers reusable LM's based at the Lunar Base while the Eagle study uses an expendable lander/ascent LM. This difference changes the true traffic model for the Eagle study. It was determined that the type of build-up phase would also severely impact the traffic model. This result was based on the differences in the Eagle and JSC scenarios. A concentrated build-up phase, like Eagle's scenario, resulted in more demanding traffic model compared to a continuous build-up phase, the JSC scenario.

8.2 Orbit Determination

The orbit selection process was very vehicle dependent. This became a major problem when the HLLV was considered - In order to use the ideal rocket equations, one must know the values of the masses of the individual stages. So, UTMD decided not to attempt to model the fuel usage of the unknown vehicle. Data on the Space Shuttle and OTV's is inconsistent from one source to another, so UTMD always selected the most conservative values for performance to avoid an overly-optimistic final product. Even modelling the reboost delta-v's is very dependent on the structure. The delta Truss was particularly challenging because of its very large surface area. Although J2 perturbation effects were included in the analysis, other factors such as local variations in the atmosphere and periodic variations due to solar radiation could not be modelled. Finally, UTMD would like to recommend that a study be done on placing Gateway above Shuttle range and using a high-powered OMV to pick up Shuttle payloads at 200 or so nautical miles and bring them up to Gateway. This may eliminate the reboost headaches.

8.3 Final Selection

The purpose of selecting a final configuration for Gateway is to help the reader visualize the activities occurring on Gateway. The final selection is an estimate rather than an exact determination, which would be beyond the scope of the project. Thus, the arrangement of the components on Gateway is one of many possibilities.

Closing

by Todd McCusker, Project Manager

Perhaps the most startling result of this study was the realization that an entirely new transportation network must be developed to support a Lunar base. This includes orbital transfer vehicles, orbital manuevering vehicles, and a new, Earth-orbiting station that is not connected to the Space Station. The design of these vehicles and the Gateway station will cost - well, who knows. Most likely, the government will be less than excited about spending a lot of money on something they feel we don't need. Currently, even the funding for our Space Station is in jeopardy. In order to make the Lunar Base and the support transportation network more palletable to our legislators, a few suggestions that popped out during our project will be given:

More research on automation is needed, particularly in the areas of OTV and OMV docking, transfering payloads from an HLLV payload to an OTV, and on-orbit fuel transfer (both from the launch vehicle to the Gateway storage tanks and from the storage tanks to the OTV's and OMV's). In addition, the processes for testing and verifying the OTV's and OMV's can probably be automated. With sufficient automation, a station like Gateway could be left unamanned, cutting the cost of constant life support systems for a crew. Data available to UTMD suggests that most of the technology for building the systems may already exist, but the technology hasn't been applied to this situation yet.

The orbital transfer vehicles and orbital manuevering vehicles must be designed and prototypes tested. Perhaps some research should be conducted in the area of combining an OMV with an OTV, so that one vehicle (call it an OTMV for Orbital Transfer and Manuevering Vehicle) is capable of firing hydrazine thrusters in the vicinity of the station, then firing its large thrusters to go to the Moon. This seems more economical than building two separate vehicles, with two different avionics systems, and two vehicles requiring maintenance. Also, several docking sequences are eliminated per mission if only one transfer vehicle is used.

Closing

When the OTV's and OMV's (or just the OTMV) are developed, the primary design goals should be minimal maintenance, maximum reliability, maximum reuseability, minimum resupply, and modularity. Performance will have to take a backseat to practicality of operations.

More research needs to be performed in the areas of fuel handling in zero g. How dangerous is LLOX in zero g? How about LH2? What if the LLOX and the LH2 were to mix in zero g after some type of accident - Would the clouds disperse quickly or linger? Would they mix well enough to become flammable? How far should a LLOX or a LH2 tank be located from Hab modules? From one another? These same questions apply to other on-orbit fuels, such as hydrazine.

In addition to the items above, which are strictly transportation-node type issues, topics like crew radiation exposure, orbital debris generation, and orbital debris protection must be further researched.

Fianally, a little more justification for building a transportation node separate from the Space Station may be in order. Many argue that the Space Station should be the focus of all American involvement in space. They feel that the Station should be a research center and be the facility where all the Lunar Base OTV's dock and the facility for building the first manned Mars vehicle and the home base of the transfer vehicles that service satellites, both civilian and military. Such a description conjures up images of some huge structure with dozens of people onboard. Current plans for the Station do not appear to accomodate these goals. For instance, most experiments slated for Space-Station type enviornments require on the order of 1*10E-06 g's maximum acceleration. A typical Shuttle to Station docking will produce around 1*10E-03 g's, or 1000 times more acceleration than the experiments can tolerate. This may be permissable if the Station is only used for docking once every 90 days or so, but a transportation node may see several dockings in an average week. In addition, the constantly shifting payloads and fuel masses will adversely affect the microgravity enviornment. Also, the storage of large quantities of OTV fuel in the vicinity of an inhabited laboratory creates unnecessary risks. For similar reasons, the construction of a Mars vehicle at the Space Station would surely put a halt to all microgravity experiments onboard. (The Mars vehicles

Closing

proposed by several universities at the 1988 Universities Space Research Association convention at KSC all required 30 to 50 flights of a 100 MT HLLV just to get the ship's mass and propellant into LEO). Certainly, the Space Station is not the answer to the transportation requirements of a Lunar Base or manned Mars mission.

Gateway was designed to fulfill the transportation requirements of the most recently proposed Lunar bases. The structure of Gateway was selected especially for its rigidity against docking and its inherent hangar space. The relatively small number of launches to bring it up to Initial Operation Condition is a small price to pay for the freedom the Space Station will achieve. Claiming that Gateway could facilitate the building of a huge Mars vehicle is a little ridiculous at this point, but the Delta Truss is expandable; Gateway could possibly be enlarged (perhaps to 2,3,4 or more times its IOC size) to meet this requirement.

A few other ideas that were uncovered during the research by UTMD are listed:

- Gateway would be the headquarters for OTV's that are used to service commercial or military satellites.

- It could be the repair center where satellites are brought back for refurbishment.

- This would be a good place to perform final assembly and fill the fuel tanks of unmanned probes destined for other planets.

- There may be an opportunity for commercial space invovement here- Let the builder of the OTV's lease the use of them to the users of the Lunar base.

Closing

In addition to allowing the Space Station to carry on its research, Gateway would be a "Second Space Station" in the sense that if something were to go wrong at the Space Station, the U.S. would not be left without a manned presence in orbit.

The research conducted by UTMD was done with the belief that we were assisting NASA in its planning stages; and we feel that the American Space program would benefit greatly from a dedicated transportation facility in low Earth orbit.

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APPENDIX A: PROPOSAL

A Proposal
for an
Earth Orbiting Transportation Node

Gateway

Submitted to:

Dr. Wallace T. Fowler

The University of Texas at Austin
Department of Aerospace Engineering
and Engineering Mechanics

Presented by:

University of Texas Mission Design:
Project Gateway

March 4, 1988

Executive Overview

Project Gateway

This document outlines the proposed design of an Earth-orbiting transportation node. The primary purpose of the transportation node (Gateway) will be to support America's Lunar Base mission. In addition, Gateway will play an instrumental role in interplanetary missions, both manned and unmanned. The University of Texas Mission Design (UTMD) group will be concentrating on the two most important aspects of such a station:

1. How will Gateway accommodate the crew, mass, and fuel throughput for the Lunar Base missions?
2. Where should Gateway be located in order to economize the operation of the Lunar Base?

UTMD will use available Lunar base buildup scenarios to predict the traffic flow through Gateway. From the traffic flow model, the number of docking ports, remote servicing arms, fuel storage tanks and crew persons needed on Gateway will be determined. UTMD will not assume that any technology that does not appear to be feasible around the year 2000 will exist.

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1.0 Summary

This section of the report provides a summary of the problem and a general description of the primary areas of research.

1.1 Background

The long range goal of the United States' space effort is to explore and colonize the Solar System... FIRST.

The initial step towards this end is establishing a Lunar Base. This will enable us to study the long term effects of low gravity on humans, test construction techniques, refine operations, and possibly produce fuel outside the gravity well of Earth.

Gateway will accommodate the high traffic expected for the support of Lunar Base Operations.

We propose to design Gateway such that most, if not all, space travel to destinations beyond Low Earth Orbit (LEO) will be economized in terms of fuel savings. Primarily, we want to minimize the rocket propellant usage in the support of a Lunar Base.

Because we are depending only on current or near current technologies, the target date for initial operation of Gateway could realistically be around the year 2000, assuming ambitious efforts to fund the project.

1.2 Operation

The Gateway station will be the hub of the Earth-Moon transportation network. Conventional vehicles, such as the NASA Space Transportation System will deliver cargo and crew to Gateway. The payload will then be loaded onto Orbital Transfer Vehicles (OTV's), which will deliver the cargo and crew to the Moon. On the lunar surface, the crew will perform scientific and resource missions for surface stays of 60 - 180 days. At the end of the work period on the moon, the crew will use an OTV to return to Gateway. They may bring products that were produced on the lunar surface. Some of these products may need to stay on Gateway, others may need to be brought to Earth or the Space Station. In addition, the Gateway crew will need to service the OTV's to prepare them for the next mission. Finally, they will take a Shuttle or another vehicle back to Earth. This scenario will be repeated many times during the buildup of the Lunar Base.

1.3 Orbit Determination

Gateway must be placed in an orbit which minimizes the overall fuel costs of the entire operation. Orbits of all possible altitudes, inclinations, and eccentricities within a reasonable set will be tested for different vehicles to determine the most fuel-efficient transportation network. Several politically stable launch sites will be compared. Both the Earth to Moon trip and the return trip will be included in the analyses.

In addition to finding an economical orbit, there is considerable concern about crew safety in various orbits. Factors such as orbital debris, the van Allen radiation belts, susceptibility to solar flares, and vulnerability to cosmic radiation are being considered.

1.4 Plan of Action

In order to design Gateway, The University of Texas Mission Design chose to reduce the transportation node to a black box.

1. How big is it? What facilities does it have? How much crew can it accommodate? How much fuel and payload can it store? How many vehicles can dock with it at any given time?
2. Where is it? What is the most economical orbit for this to be in?

To facilitate this approach, the company divided into two teams: the Operations Team, which address the first questions above; and the Orbit Determination Team, which address the second set of questions.

1.5 Bottom Line

From our analyses, The University of Texas Mission Design Gateway Project will produce an outline of the expected requirements for an Earth orbiting transportation hub. These requirements will include crew, mass and fuel throughput in a timeline form. The timeline will begin with the initial buildup of Gateway, noting the minimum structural components required to support the first Lunar Base mission.

As the Lunar Base grows, Gateway will have to expand also. This process will be detailed in the final report, along with any requirements for possible interplanetary missions. Moreover, the final report will designate the one orbit that is the most desirable for Gateway, taking into account crew safety, fuel savings, and launch site availability. Additionally, several alternate orbits will be chosen which may prove to be viable alternatives to the primary recommendation. As the time-dependent growth of Gateway is determined, a series of sketches or a scale model will be presented to demonstrate a possible configuration for Gateway in the chosen orbit.

2.0 Technical Proposal

This portion of the proposal covers the research being performed by the Operations Team and the Orbital Determination Team.

2.1 Operations Team Technical Proposal

The objectives of Gateway are to (1) support cargo and crew transfer between a low Earth- and low lunar- orbit (LEO and LLO), (2) support vehicle assembly and testing for manned interplanetary missions, and (3) house and maintain the vehicles and crew necessary to achieve these goals. These objectives will be sensitive to the efficiency and affordability of the design, as well as crew safety considerations.

2.1.1 Problem Approach

Figure 1 below shows a top-down diagram of the Operations Team's approach to the sizing of Gateway's structure. First, the mission requirements will be determined. These requirements include cargo and crew transfer for the Lunar Base, on-orbit construction of interplanetary vehicles, and possibly satellite repair and space-station support.

Sizing Process

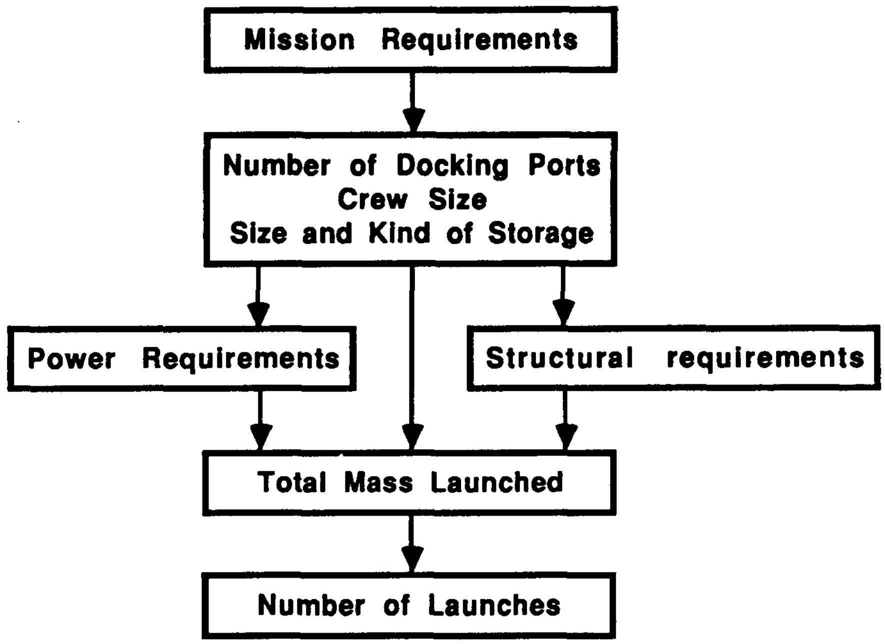


Figure 1: Sizing Process

These basic requirements will determine the number of OTV's and docking ports needed, along with minimum crew size and storage capacity. Using these results, power- and some structural- requirements will then be determined. The total amount of mass comprising Gateway and the number of launches needed to get the port operational will then be calculated.

2.1.2 Preliminary Results

The Operations team has been researching several areas to determine Gateway's structural requirements. Work is currently in progress on a Lunar Base traffic model for the space-port, transportation vehicle requirements, and various other structural and safety considerations.

2.1.2a Lunar Base Traffic Model

A Lunar Base software model developed by Large Scale Programs Institute (LSPI) is being utilized to determine the amount and types of cargo to be brought through Gateway, using the baseline Lunar Base scenario released by the Johnson Space Center in December 1987. The software outputs the amount of materials being transferred from the Earth to Moon on a year by year basis for Lunar Base build-up and steady state operation. Other outputs include the number of orbital transfer vehicles (OTV's) required to transfer mass to the moon, fuel required for this task, and Lunar Base crew transfer information.

In addition, another, more aggressive, Lunar Base scenario is being considered. Eagle Engineering's Lunar Base study will also be worked through the LSPI software, to output the same information as from JSC's scenario. Eagle's study will also be hand-processed to help verify the software models. These two Lunar Base scenarios should effectively provide upper and lower bounds on Gateway's projected traffic profile and therefore identify Gateway sub-systems that are most affected by different traffic profiles.

2.1.2b Transportation Vehicles

A launch vehicle data base has been prepared to facilitate decision-making in regards to feasible near-future launch capabilities. The current space shuttle and Titan rockets are being considered, as well as Rockwell's shuttle-derived vehicle and several proposed HLLV's. A summary of this data base is shown in Table 1 in the appendix.

A similar data base, detailing proposed OTV's, is in preparation. This database will detail the payload and delta-V capabilities of the different craft, Isp, and also list maintenance requirements such as projected down-time for repair and overhaul, and the man-power and facilities needed for this. The crew required to transfer cargo and refuel the transfer vehicles is another item of study.

2.1.2c Structural Elements

In-depth research is in progress on structures developed for Space-Station use. Gateway and the proposed U.S. Space Station have many common structural objectives which makes this research highly efficient.

There are four basic elements of the Gateway structure: (1) Pressure vessels, used for fuel storage, habitation, command and communications, and proximity operations control; (2) External Activity Zones, used for docking, service and assembly, storage and OTV hangar space, and payload integration; (3) Power Supply and Radiators, to produce energy and reject excess heat; and (4) the actual Truss Structure, which provides interconnection and support for the rest of the space-port.

The Gateway structure will be chosen not only for performance and controllability, but also for ease of assembly and future growth capabilities. Important factors in the design are commonality and maintainability, as well as separate external work/storage zones to help insure crew safety.

Crew safety considerations necessitate research in several other areas, also. Cryogenic storage and fuel handling are two such critical items.

Radiation is another safety concern. Depending on its orbit, Gateway may either pass through the Van Allen belts on occasion, or possibly reside above them. Heavy shielding is necessary in living quarters and EVA gear if the space port will periodically be bombarded with Van Allen radiation. Above these belts, solar flares are a problem. Quick access "safe havens" must be devised to protect crew in this event.

2.2 Orbit Determination Team Proposal

The Orbit Determination Team is dedicated to selecting a suitable orbit for the Gateway station.

2.2.1 Transportation Network

Gateway will play a key role in enabling clients to frequently and economically move crew and equipment between the Earth's surface and the Moon. But exactly what will its role be?

The following sections describe the expected transportation networking between the Earth's surface, a LEO/Space Station orbit, Gateway, and the Moon. Figure 2 diagrams the various transportation options being considered for the overall transportation system.

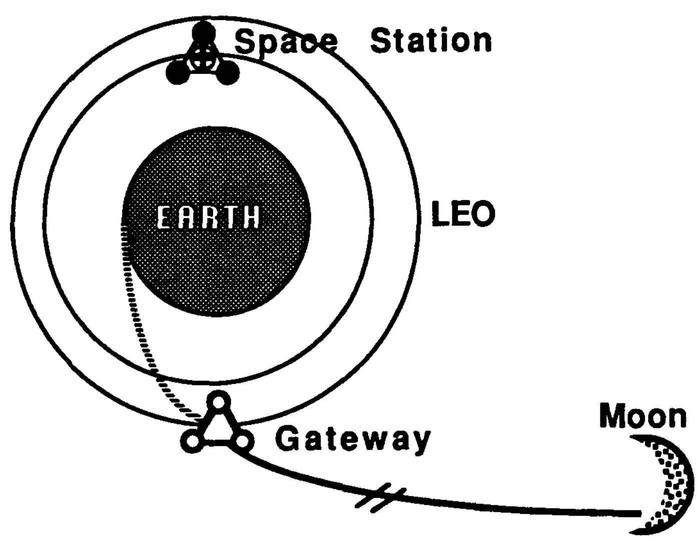


Figure 2: Network

2.2.1a Network Flow

Launch to Gateway

The first and most expensive step in going to the Moon is leaving the Earth. Once the launch vehicle (Shuttle or heavy lift launch vehicle (HLLV)) has propelled the payload to LEO, the launch vehicle can dock with Gateway and exchange cargo if Gateway is also in LEO.

However, if Gateway is placed in a higher orbit which is beyond the maximum altitude of the launch vehicle, an orbital transfer vehicle (OTV) will dock with the launch vehicle. The cargo will be loaded on to the OTV which will then carry it up to Gateway.

Landing from Gateway

In bringing back cargo and crew from the Moon, the final leg of the journey will be from Gateway to the Earth's surface.

If Gateway is placed within the range of the shuttle, then the shuttle could be used to move both crew and cargo. However, the shuttle is not efficiently used if only cargo is to be ferried. In the case of cargo only transfer, an aerobraking landing vehicle similar to the shuttle could be developed which would strictly carry cargo with no provisions for crew.

If Gateway is placed past the shuttle's range, provisions must be made to transport crew via an OTV to a rendezvous with the shuttle which would then carry them to the surface. The landing vehicle mentioned above could be used to ferry down other cargo directly to Earth.

Transfer to Moon

Cargo and crew on Gateway which are destined to the Moon will be transferred to an OTV. When a launch window opens, the OTV will begin its lunar transfer trajectory. Upon approach to the Moon, the OTV will be inserted into the orbit which requires the least fuel.

Transfer to Space Station

For cargo and crew which travel between the Space Station and Gateway, one or more OTV can be permanently assigned. A Gateway orbit which is identical to the Space Station orbit would be the easiest to perform.

2.2.1b Lunar Orbit

The orbit into which the OTV enters about the Moon will affect the Gateway's placement. Since the primary purpose of Gateway is to serve as a transportation node for Earth-Moon missions, the Gateway orbit design should be sensitive to the destination lunar orbit motions.

Whether or not there is transportation node in lunar orbit will not be considered. Only the behavior of the lunar orbit is important, not the presence of a station.

Polar

One lunar orbit which will be researched is a lunar polar orbit. A regressing polar orbit has the advantage of covering the entire of the Moon approximately every 14 days. Insertion into a polar orbit guarantees that a landing site will periodically lie in the plane of the orbit, thereby eliminating the need for a descent plane change if there is no rush to reach the surface.

L2

Another possible lunar orbit is the L2 Earth-Moon point. While this is not a stable libration point, a halo orbit can be established about the point. We will briefly study the benefits of this point from a fuel and time perspective.

2.2.2 Constraints

The following topics are among those being regarded as restrictive to the orbit.

2.2.2a Launch Sites

Geographic considerations are:

1) No launches which can endanger a populated area

2) Body of water required to ditch tanks or boosters

Launch sites being considered are KSC, Hawaii, and French Guiana in South America. KSC is currently the only available American launch site. Hawaii is being considered because it is geographically the lowest point in the U.S. at a latitude of approximately 20 ° North. Since the plane of the moon varies from a latitude of 18.5 ° to 28.5 °, the maximum the required plane change would ever be from Hawaii is approximately 2°. French Guiana is currently a launch site for the European Space Agency (ESA). French Guiana has very close to an equatorial latitude and would involve no plane change for virtually any orbit. A United States Launch site would be preferable although. In addition to geographic considerations, abort provisions must also be considered.

2.2.2b Safety

There are several orbit considerations that are strictly a matter of safety. These include orbital debris, the Van Allen radiation belts, and cosmic radiation and solar flares.

Debris

Orbital debris represents a significant safety concern for any type of permanent space structure. The amount of debris has escalated at the rate of 13%/yr since 1966. Collisions among debris in orbit produce smaller debris capable of repeating this cycle. The real danger lies in the fact that most of these collisions will be "high energy" impacts. The average impact velocity of 10 km/s ensures that almost all of the collisions will exhibit hypervelocity impact characteristics. Both objects will be subjected to very high instantaneous pressures with the strong shock waves causing melting and possible vaporization in the region of the hole.

Van Allen Belts

Another safety consideration is the high intensity radiation bands that encircle the earth. These two concentric belts are known as the inner Van Allen radiation belt and the outer Van Allen radiation belt. The inner belt stretches from about 500 to 2500 miles at a latitude of +/- 20° with a maximum intensity occurring at about 1800 miles. The outer belt has a range of 8000 to 20,000 miles for latitudes of +/- 50 ° and peaks at about 12,000 miles.

Cosmic and Solar Radiation

Cosmic radiation and solar flares also present a potential health hazard to the crew. This topic and allowed dosages/time of radiation are still being researched.

Escape

A possible function of Gateway is to serve as a safe escape for Space Station crew. A pressurized emergency area can be included on Gateway which can be used as a temporary waiting station for eventual rescue by other vehicles.

In order to serve this purpose, Gateway must be in an orbit which does not require a great travel time to reach. However, Gateway should not be so close to the Space Station that fumes and heat from Gateway traffic interfere with experiments aboard the Space Station.

2.2.2c Atmospheric Drag

The minimum acceptable altitude for Gateway will depend on the mass and surface area of the structure generated by the operations group and a 90 day reboost safety margin. This safety margin means that the structure must be able to remain aloft for at least 90 days without a reboost burn.

2.2.2d Nuclear Safe

The assumption for a nuclear safe orbit will be an orbit such that the structure will not reenter for a period on the order of 250 years, thus allowing time to somehow boost the defunct structure into a higher orbit in the event of a nuclear accident.

2.2.3 Considerations

In addition to the constraints on the orbit, the following items need to be considered also:

2.2.3a Delta V

With the propulsion systems in use today, the velocity changes required of a mission greatly determine the mission's feasibility. Vehicles which can produce enough velocity change (delta V) to lift a large payload into Earth orbit are extremely expensive and complicated. As the altitude of the payload destination orbit increases, the needed delta V increases exponentially. Conversely, the amount of delta V required to maintain Gateway in orbit decreases exponentially as orbit altitude increases.

The Gateway orbit should be placed in an orbit which minimizes the total delta V needed to both deliver payload to Gateway and maintain the orbit. To determine the orbit of best compromise, software will be used to calculate the total delta V sensitivity to variation of different orbital parameters.

Figure 3 below is a example plot of the two contrasting trends of mass consumption (fuel) versus altitude. The optimum altitude considering these two weighted trends occurs at their intersection. Analysis of plots similar to Figure 3 will allow for design of an orbit which requires a minimum delta V considering several influences.

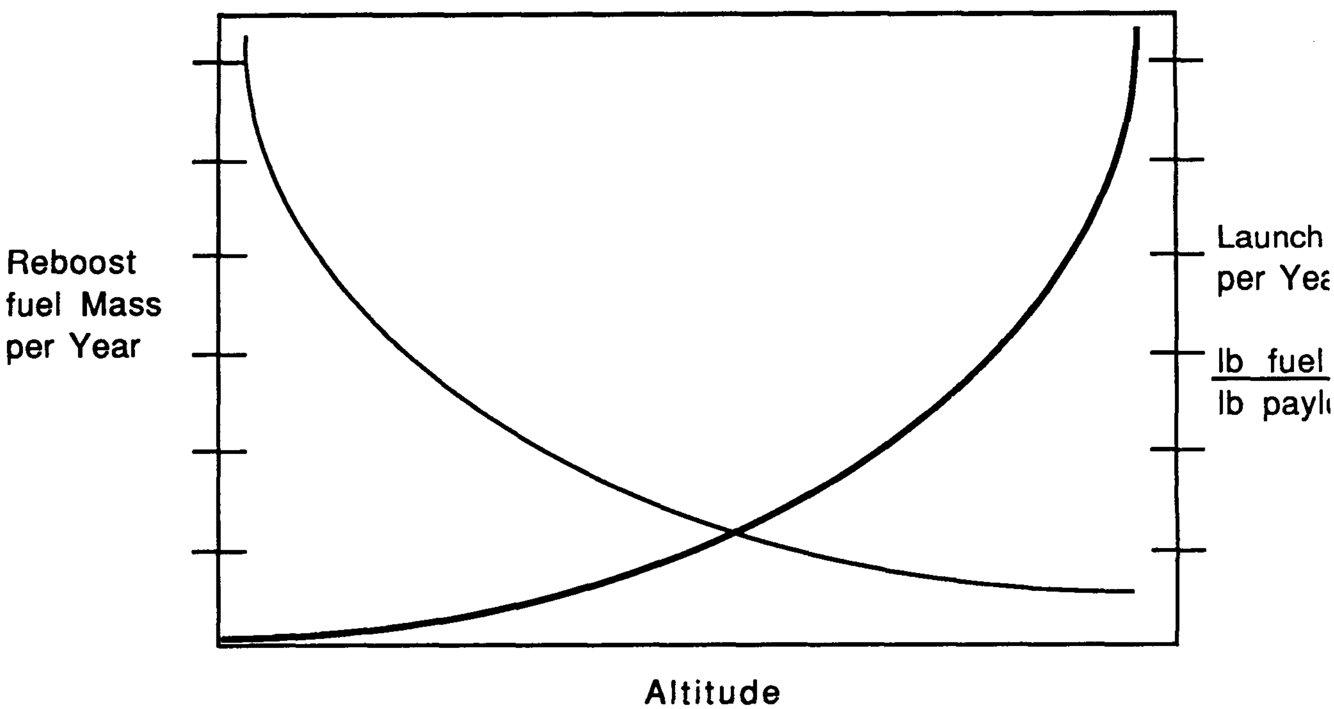


Figure 3: Mass Tradeoff

2.2.3b Launch Windows

Earth-Gateway and Gateway-Moon trajectories will be optimized to produce maximum time slots for vehicle launch. The accessibility of Gateway to users must be convenient before realistic scenarios involving Gateway can be planned.

The frequency and duration of launch windows is a design condition which is affected primarily by the following parameters:

1. Nodal regression of Gateway orbit
2. Lunar orbit period about Earth
3. Nodal progression of Lunar orbit

2.2.3c Lunar Orbit Inclination Variation

Every eighteen (18) years the moon's orbit around the Earth cycles through a period during which the inclination alternates between 18.5° and 28.5°. Therefore, mission design parameters between Gateway and the Moon will also vary if the inclination of Gateway is constant. The impact of varying the Gateway orbit inclination to match the Moon will be studied with respect to its influence on other design considerations.

2.2.4 Analysis/Approach

The analytical approach that has been taken to determine the best possible orbit consists of two major steps.

The first was to examine possible orbits between 0° and 180° inclinations and 100 nautical miles to 157,000 nautical miles altitude. Delta V requirements and launch window limitations will be compared for Gateway supported missions to the Earth's surface, the space station, and a Lunar Base. From this rough analysis, approximately six (6) optimal orbit candidates will be selected.

The second step will be to subject these orbits to a more detailed analysis which will take into account launch vehicles, launch sites, orbital vehicles, and various Lunar Base mass transfer scenarios. From this analysis a final orbit will be selected which best suits the needs of the scenario that has been developed by the operations team.

2.2.4a Rough Analysis

The preliminary analysis will consist of FORTRAN programs which will generate tables of data to be down loaded and plotted using a Macintosh. The programs will have two nested loops. The outer loop will vary inclinations from 0° up to 180°, and the second loop will run through altitudes from 100 nmi up to 157,000 nmi. The inclinations will be in ten degree (10°) steps and the step size of the altitudes will vary so as to obtain more data at the lower altitudes where small increments will have more effect than at higher altitudes.

The data will be generated in the form of a table. The first column will contain the altitudes that were examined. The second column will contain either the corresponding delta V or launch window per year for a 0° inclination. The third column will contain the same data for a 10° inclination and so on up to 180°. The delta V and launch window analysis will be carried out for four trajectories:

launch to Gateway,
landing from Gateway(aerobraking),
transfer to the Space Station,
and transfer to the moon.

In all eight tables and corresponding plots will be generated. After examining the plots, the preliminary orbital candidates will be selected.

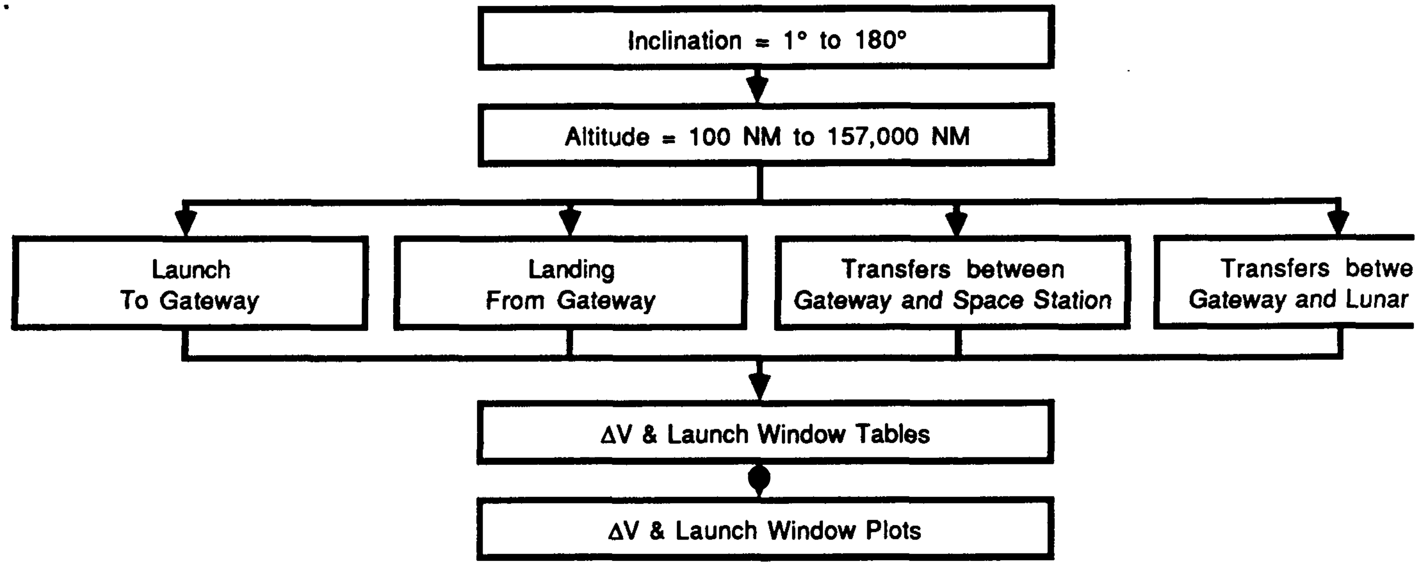


Figure 4: Preliminary Analysis

Delta V

The orbit which gives the minimum delta V requirements would be the best orbit. However since the traffic flow model is as yet unknown, it will not be possible to determine the total delta V requirements at this stage. Therefore, the task will be to find at least four to six orbits which minimize the fuel to launch from the Earth, to land on the Earth, to transfer to the space station, and to transfer to the moon. At this level of the analysis, delta V is the most important factor.

Launch Windows

The launch window availability to each of the four destinations (ie. Earth launch, Earth landing, Space Station transfer, and lunar transfer) will be used to narrow the selection of orbits. For example if two different orbits have similar delta V requirements they may have different launch window frequencies. Therefore with the higher launch window frequency will therefore be the more desirable. Launch window availability is not expected to differ dramatically except possibly to transfer to the space station.

2.2.4b Detailed Analysis

The detailed analysis will primarily be done in four separate spread sheets, one for each of the four cases:

1. launch to Gateway,
2. landing from Gateway,
3. transfer from Gateway to the Space Station,
4. transfer from Gateway to the moon.

Each spread sheet will compare at least six orbit candidates from the previous analysis. The major factors which will be examined per mission are: delta V, payload, total costs, launch windows, crew requirements, and fuel needs. The characteristics of different vehicles will examined to select those best suited for each design scenario.

3.0 Management Proposal

This section provides a description of the Project Gateway company structure.

3.1 Overview

The University of Texas Mission Design Project Gateway realizes the need for a clean and efficient company structure and the need to fit the structure specifically to the task. Because we are taking a black box approach to the Gateway problem (outlined in Sec. 1.4) , two teams were formed under the Project Manager. These two teams individually address the two major areas of research. The Operations Team is primarily dedicated to determining the mass and crew throughput for Gateway, while the Orbit Determination Team is dedicated to finding the most economical orbit for Gateway. The company structure of Project Gateway is shown Figure 6.

The primary job of the Project Manager is to coordinate the efforts of the other members toward the common goals of the project. The group is small enough that the Project Manager can maintain direct communication with all the other members on a day-to-day basis.

Both the Operations Team and the Orbital Determination Team have their own Team Leader. The Team Leaders primarily keep their Team working together in addition to performing their engineering tasks. The other Team Members are free of most administrative responsibilities and can concentrate their efforts on research and engineering. Each member performs his own library searches and speaks directly with any consultants in their technical area. At the end of every week, each Team Member presents a summary of the work they have completed in the past week, and an outline of what they expect to accomplish the next week to their Team Leader. The Team Leaders summarize the reports they have received and meet with the Project Manager to discuss the progress of the project and any problems that may be surfacing. The entire group is then updated on the state of the project by the Program Manager and any new tasks are formally assigned to the members. These group meetings occur at least three times a week.

3.2 Critical Path

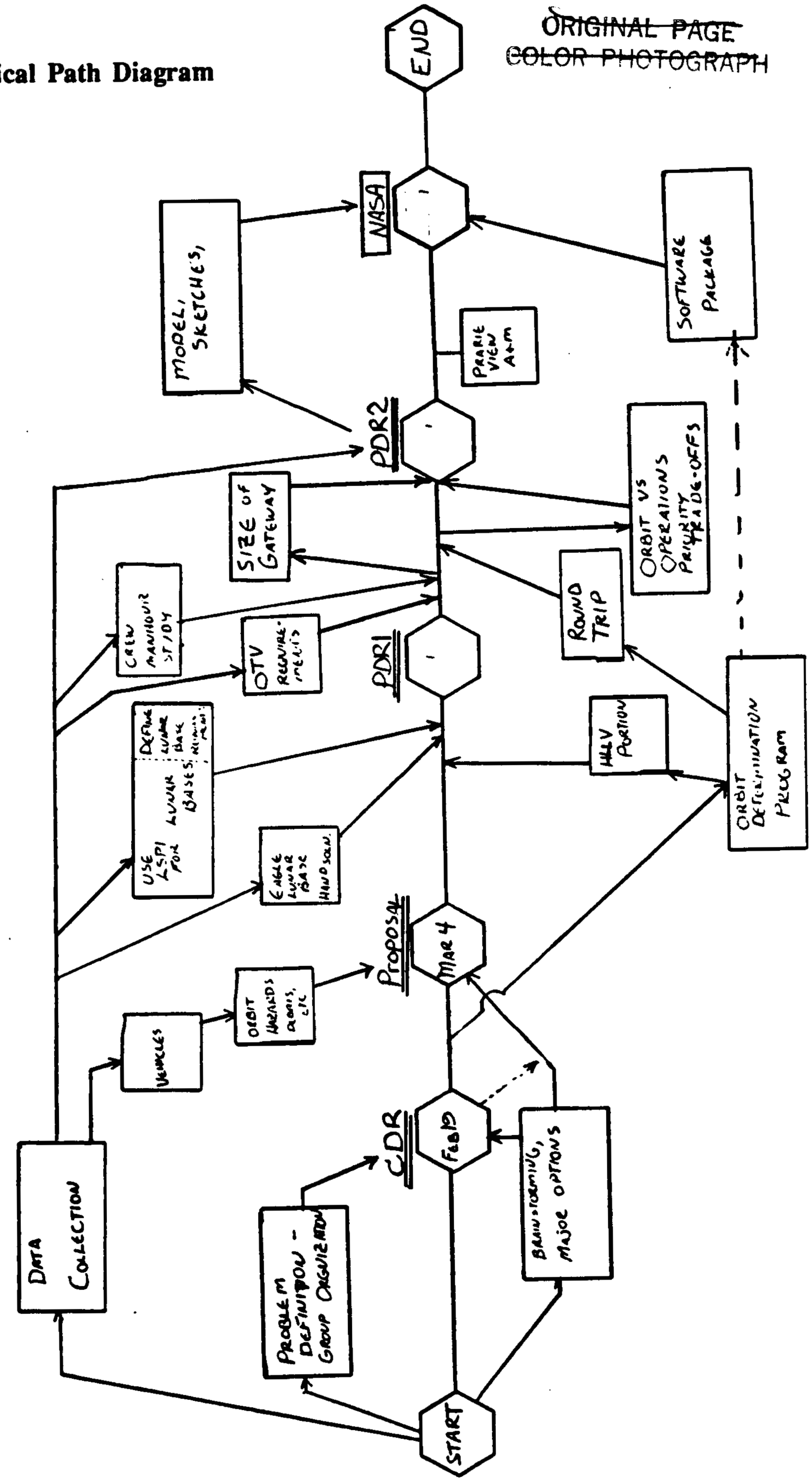
The project will follow the design path shown in Figure 5. Milestones are shown in the hexagons which lie on the line.

3.3 Scheduling

Table 2 is the timeline being followed. The expected duration of specific tasks is shown by the darkened horizontal line next to the names and numbers of the tasks.

The tasks assigned to each Team Member are outlined in Table 3. This chart is used as a guide to monitor the activities of the Engineers as well as those of the Team Leaders and Program Manager.

Figure 5: Critical Path Diagram



University of Texas Mission Design: Project Gateway

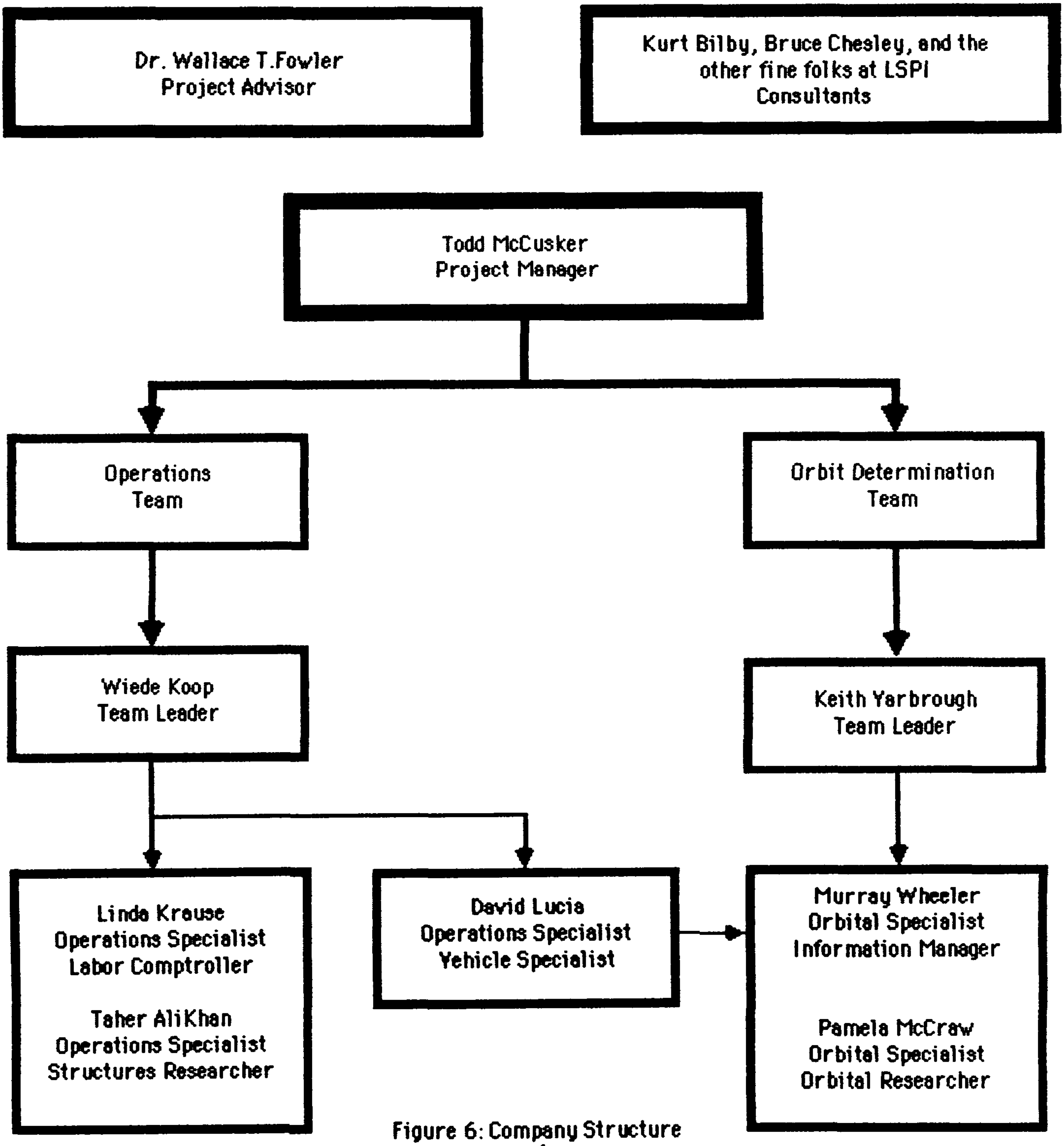


Figure 6: Company Structure

4.0 Cost Proposal

The itemized and overall costs of the research at Project Gateway are presented in this section of the proposal.

4.1 Personnel Cost Estimate

Pay scales were provided in the Request for Proposal. The total number of hours per employee per week are estimated based on work done in the first three weeks of the project. The table below shows personnel costs.

Formulation of Projected Personnel Costs

Weekly breakdown:					
1	Project Manager	@ $25/hr	13 hrs/wk	$	325
2	Technical Directors	@ $22/hr	11 hrs/wk	$	484
5	Engineers	@ $15/hr	9 hrs/wk	$	675
	Technicians	@ $10/hr	2 hrs/wk	$	20
	Secretaries	@ $6/hr	3 hrs/wk	$	18
	Graphics	@ $6/hr	2 hrs/wk	$	12
	Weekly Subtotal			$	1534
Projected Cost for 14 weeks				$	21,476
	Technical Consultants	@ $75/hr	15 hrs	$	1125
	Management Consultants	@ $75/hr	2 hrs	$	150
Total				$	22,751
Plus 10% Error				$	2,275

Total Projected Personnel Cost: $ 25,030

4.2 Material and Hardware Cost Estimate

The material and hardware cost estimates are based on expenses incurred to date and those of previous design groups. These expenses are presented below.

Anticipated Materials and Hardware Costs

4 months rent of Macintosh+ and peripherals	$	600
4 months rent of IBM PC-AT and peripherals	$	1400
Software	$	50
CDC Mainframe time	$	50
Copies (@ $0.05 per copy)	$	300
Transparencies (@ $0.50 per copy)	$	40
Miscellaneous Supplies	$	30
Subtotal	$	2470
Plus 10% Error	$	250
Total	**$**	**2720**

4.3 Total Estimated Costs

Personnel Costs	$	25,030
Materials and Hardware Costs	$	2,720
Grand Total (Proposed)	**$**	**27,750**
		(in 1988 Dollars)

5.0 References

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3. Summerfield, Martin, Editor, Space Stations and Space Platforms- Concepts, Design, Infrastructure, and Uses, New York: American Institute of Aeronautics and Astronautics, 1985.
(Engr. Library: TL 507 P75 V.99)

4. "Space Station Flight Definition and Operations Plan" (Review Draft), NASA Code SSPO-SSU-XXX, Lyndon B. Johnson Space Center, Houston, Texas, October 9, 1987.

5. "Space Transportation Nodes - Assumptions and Requirements", Eagle Engineering, Inc., Houston, Texas, EEI Report 87-174,
December 8, 1987.

6. "Mission and Operations Modes for Lunar Bases". Woodcock, Gordon R. Woodcock, Lunar Bases and Space Activities of the 21st Century, ed. Mendell, W.W., Lunar and Planetary Institute, 1985.

7. "A Moon Base/Mars Base Transportation Depot". Woodcock, Gordon R. Woodcock, Lunar Bases and Space Activities of the 21st Century, ed. Mendell, W.W., Lunar and Planetary Institute, 1985.

APPENDIX B: FLUID LOOP CONTROL SYSTEM

The Fluidic Momentum Controller (FMC) is recommended as an attitude controller for Gateway. The following is an excerpt from a design and analysis of a Fluidic Momentum Controller:

> "Fluidic Momentum Controller theory is based on the concept of conservation of angular momentum. The FMC consists basically of a loop of tubing located around the periphery of the space structure and a fluid pump. As the pump accelerates the fluid through the tubing, it increases the angular momentum of the fluid. This accelerating process acts as torque on the fluid loop. Because of conservation of angular momentum, the fluid loop then imparts a torque on the structure which is equal in magnitude and opposite in direction. Thus, if an externally applied torque acts on the body, a controller can instruct the pump to accelerate the fluid through the tubing. The torque caused by this acceleration imparts an equal and opposite torque on the structure which effectively counteracts the externally applied torque. By placing fluid loops on the three faces of the structure, three axis attitude control can be accomplished.
>
> "The advantages of the FMC are numerous. The FMC provides a high output torque with high energy efficiency and low system mass. In fact, these energy and weight efficiencies are improvements over the other conventional devices. The FMC operates at a low energy density level, thus precluding the risks associated with high energy operation. It is capable of storing large amounts of angular momentum and provides fast response time. Since the controller is mounted around the periphery of the structure, it does not take up valuable space, and it also transmits little or no vibrations to the structure. The FMC will readily absorb heat energy. Thus, it has promise as a space station waste heat management/rejection device by absorbing heat energy and rejecting it into open space. Finally, the FMC can provide optimum structure balancing by adjusting the spatial distribution of fluid mass. It can do this by independently varying one holding tank's fluid level at the expense of another." [16]

APPENDIX C: LAUNCH VEHICLE DATA BASE

LAUNCH VEHICLES	COMPANY	STATUS	OPS DATE	CREW	PAYL LEO (kg)	PAYL GEO (kg)	GLOW (kg)
SPACE SHUTTLE	ROCKWELL	OPER	1980.00	4.00	29483.35	?	2036900.00
SHUTTLE C	ROCKWELL	DEVLP	?	0.00	45000.00	TBD	2036900.00
HLV	TBD	STUDY	?	0.00	181436.00	TBD	3900874.00
SDV-2	TBD	STUDY	?	0.00	136077.00	TBD	TBD
SDV2 (II)	BOEING	DEVLP	1995.00	0.00	88450.05	22679.50	TBD
SDV1	BOEING	DEVLP	1995.00	0.00	65770.55	8618.21	TBD
ET1	BOEING	DEVLP	1995.00	0.00	39462.33	6622.41	TBD
ET2	BOEING	DEVLP	1995.00	0.00	31751.30	6622.41	TBD
SRB-X	USA	STUDY	1989.00	0.00	19050.78	4989.49	1688800.00
TITAN 34D TS	M MARIETTA	OPER	?	0.00	14923.11	1791.68	670406.02
TITAN 34D/7	M MARIETTA	DEVLP	?	0.00	17145.70	3175.13	866356.90
TITAN 34D IUS	M MARIETTA	OPER	1982.00	0.00	14923.11	1927.75	689275.36
TITAN 34D	M MARIETTA	EXIST	?	0.00	15875.65	TBD	676847.00

LAUNCH VEHICLE	STAGE 1				STAGE 2			
	WEIGHT TL (kg)	PROP WGHT (kg)	ISP (sec)	THRUST (KN)	WEIGHT TL (KG)	PROP WGHT (KG)	ISP (sec)	THRUST (KN)
SPACE SHUTTLE	748240.00	716030.00	455.00	6271.96	92530.00	10840.80	316.00	53.38
SHUTTLE C	748240.00	716030.00	455.00	6271.96	N/A	N/A	N/A	N/A
HLV	TBD	932127.00	461.00	13967.35	N/A	N/A	N/A	N/A
SDV-2	TBD	TBD	455.00	6271.96	N/A	N/A	N/A	N/A
SDV2 (II)	TBD	718032.97	455.00	6271.96	N/A	N/A	N/A	N/A
SDV1	TBD	566980.00	455.00	3712.46	N/A	N/A	N/A	N/A
ET1	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
ET2	TBD	TBD	TBD	TBD	TBD	TBD	452.20	TBD
SRB-X	106590.00	90718.00	TBD	5337.84	TBD	TBD	318.00	449.26
TITAN 34D TS	TBD	TBD	302.00	2353.10	TBD	TBD	318.00	449.26
TITAN 34D/7	TBD	TBD	302.00	2353.10	TBD	TBD	318.00	449.26
TITAN 34D IUS	TBD	TBD	302.00	2353.10	TBD	TBD	318.00	449.26
TITAN 34D	TBD	TBD	302.00	2353.10	TBD	TBD	318.00	449.26

LAUNCH VEHICLE	STAGE 3				STAGE 4			
	WEIGHT TL'ROP (KG)	WGHT (KG)	ISP (sec)	THRUST (KN)	WEIGHT TL ROP (KG)	WGHT (KG)	ISP (sec)	THRUST (KN)
SPACE SHUTTLE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SHUTTLE C	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
HLV	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SDV-2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SDV2 (II)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SDV1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ET1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ET2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SRB-X	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TITAN 34D TS	12394.80	10738.74	309.50	71.17	N/A	N/A	N/A	N/A
TITAN 34D/7	23994.91	20638.35	446.40	133.45	N/A	N/A	N/A	N/A
TITAN 34D IUS	10840.80	9706.83	293.20	200.17	3900.87	2766.89	320.60	75.62
TITAN 34D	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

LAUNCH VEHICLE	STRAP-ONS				
	NUMBER	WEIGHT (KG)	TL'ROP WGHT (KG)	ISP (sec)	THRUST (KN)
SPACE SHUTTLE	2	1177000.00	503077.00	281.01	27578.84
SHUTTLE C	2	1177000.00	503077.00	281.01	27578.84
HLV	4	TBD	TBD	321.00	7406.25 X 4?
SDV-2	2	TBD	2101482.50	TBD	TBD
SDV2 (II)	2	1177066.00	503076.67	281.01	27578.84
SDV1	2	1177066.00	503076.67	281.01	27578.84
ET1	2	TBD	TBD	TBD	TBD
ET2	2	TBD	TBD	TBD	TBD
SRB-X	2	1177066.00	503076.67	281.01	27578.84
TITAN 34D TS	2	488062.84	TBD	265.00	10675.68
TITAN 34D/7	2	585131.10	TBD	265.00	12454.96
TITAN 34D IUS	2	488062.84	TBD	265.00	10675.68
TITAN 34D	2	TBD	TBD	265.00	10675.68

APPENDIX D: OTV DATABASE

Characteristic	Vehicle Tpye			
	ONE-STAGE OTV UNMANNED	NE-STAGE OTV MANNED	WO-STAGE OTV UNMANNED	WO STAGE OTV MANNED
COUNTRY	?	?	?	?
COMPANY	?	?	?	?
CREW CAPACITY	0	4	0	4
ISP (sec)	480.00	480.00	480.00	480.00
FUEL TYPE	LH2/LO2	LH2/LO2	LH2/LO2	LH2/LO2
LO2 CAPACITY (kg)	58200.00	58900.00	50200.00	50400.00
LH2 CAPACITY (kg)	8400.00	8500.00	7200.00	7700.00
REUSABLE?	YES	YES	YES	YES
LIFETIME (YEARS)	5.00	5.00	5.00	5.00
USES PER LIFETIME	15.00	15.00	15.00	15.00
SERV INTERVAL (DAYS)	45.00	60.00	45.00	60.00
HRDWARE SUPPLY /MISSI (kg	500.00	750.00	500.00	750.00
PAYLOAD LEO TO LLO	42000.00	35200.00	35000.00	28000.00
TOTAL VEHICLE MASS (fueled	112900.00	112900.00	112900.00	112900.00
VEHICLE DIMENSIONS (m)	15 X 13	15 X 17	15 X 26	15 X 30

Characteristic	Vehicle Type		
	1-WAY TV 11-DAY	1-WAY TV 20-DAY	1-WAY TV 94-DAY
COUNTRY	?	?	?
COMPANY	?	?	?
CREW CAPACITY	0	0	0
ISP (sec)	9000.00	3000.00	5000.00
FUEL TYPE	LOW THRUST	LOW THRUST	LOW THRUST
LO2 CAPACITY (kg)	N/A	N/A	N/A
LH2 CAPACITY (kg)	N/A	N/A	N/A
REUSABLE?	NO	NO	N0
LIFETIME (YEARS)	0.00	0.00	0.00
USES PER LIFETIME	1.00	1.00	1.00
SERV INTERVAL (DAYS)	10.00	10.00	10.00
HRDWARE SUPPLY /MISSI (kg	0.00	0.00	0.00
PAYLOAD LEO TO LLO	10000.00	40000.00	120000.00
TOTAL VEHICLE MASS (fueled	12600.00	129000.00	170000.00
VEHICLE DIMENSIONS (m)	?	?	?

APPENDIX E: PERSONNEL

Taher M. Ali Khan

Local Address:
8407 Appalachian Dr.
Austin, Texas 78759
(512) 346-2248

Permanent Address:
4474 Windsor Oaks Dr.
Marietta, Georgia
(404) 928-4000

Classification:	Senior
Major:	Aerospace Engineering
Option Area:	Space Flight
Specialty Area:	Structural Analysis
Graduation date:	August, 1988
Gateway Job Title:	Traffic Specialist

Contributions to Project Gateway
- Modelling expected traffic through Gateway
- Obtaining documentation for the Lunar Base support and operations and for the OTV turnaround analysis

Experience
June 1986 to January 1988 - Cooperative Engineering Program, Eagle Engineering, Inc., Houston, Texas. Three semesters of full-time employment totalling thirteen months. Provided engineering and technical support for the Advanced Space Transportation System contract involving the Lunar Base study.

Future Plans:
Graduate Student, University of Texas at Austin, Aerospace Engineering Department - Structural Mechanics

Quotes "That's what I've been tryin' to tell you.. Eagle did a study like that already"
"Those numbers, they're bogus"

Wiede Koop

Local Address:
2703 Swisher #102
Austin, Texas 78705
(512) 477-9270

Permanent Address:
Rt. 1, Box 515
Edna, Texas 77957
(512) 782-2800

Classification:	Senior
Major:	Aerospace Engineering
Option Area:	Space Flight
Specialty Area:	Structures
Graduation date:	May, 1988
Gateway Job Title:	Operations Team Leader

Contributions to Project Gateway
- Operations team management
- Crew man-hours determination
- Final Gateway sizing

Experience
Engineering Co-op, NASA/Johnson Space Center, total of 18 months between January 1985 and May 1987, four months in the Aircraft Operations Division, the remainder in the Structures and Mechanics Division.

Future Plans:
Associate Engineer, Structural Analysis Section, The Dee Howard Company, San Antonio, Texas.

Linda Krause

Local Address:
2703 Swisher #102
Austin, Texas 78705
(512)477-9270

Permanent Address:
3329 Riveroad Ct. #311
Fort Worth, Texas 76116
(817)735-8616

Classification:	Senior
Major:	Aerospace Engineering
Option Area:	Space Flight
Specialty Area:	Structural Mechanics
Graduation date:	May, 1988
Gateway Job Title:	Structures Specialist

Contributions to Project Gateway
- Configurations and Power Systems Research
- Final Gateway Sizing
- Project Budgeting

Experience
Materials Analyst, Summers 1986 and 1987, State Dept. of Highways and Public Transportation, Division of Materials and Tests.

Future Plans:
Associate Engineer, General Dynamics Fort Worth Division
Materials and Processes Technology Laboratory, Composites Group

David Lucia

Local Address:
3001 Medical Arts #213
Austin, Texas 78705
(512) 478-6519

Permanent Address:
414 Duck Lake
Austin, Texas 78734
(512) 261-4106

Classification:	Senior
Major:	Aerospace Engineering
Option Area:	Space Flight
Specialty Area:	Structural Mechanics
Graduation date:	May, 1988
Gateway Job Title:	Transportation Engineer

Contributions to Project Gateway

- Operations Team
- Transfer vehicle and launch vehicle fleet
- OTV maintanence requirements and turnaround time
- Cryogenic fuel storage on Gateway

Experience

Vice Commander, University of Texas AFROTC Detachment 825

Future Plans:

Astronautical Engineering in United States Air Force, Air Force Systems Command, Wright Patterson AFB, Dayton, Ohio.

Pamela McCraw

Local Address:
1801 Rio Grande #201
Austin, Texas 78701
(512) 472-8312

Permanent Address:
10455 Martha Lane
Beaumont, TX 77706
(409) 892-5252

Classification:	Senior
Major:	Aerospace Engineering
Option Area:	Space Flight
Specialty Area:	Orbital Mechanics
Graduation date:	May, 1988

Gateway Job Title: Orbit Specialist

Contributions to Project Gateway
- Orbit Determination Team

Experience
Summer 1984,1986,1987, Spring & Fall 1985 NASA-JSC, Coop

Future Plans:
Permanent employment with NASA-JSC beginning June 1988

Quotes "I circled Disch Falk Field for about half an hour"
"Linda, is that you?"

Todd McCusker

Local Address:
101 E. 33rd #203
Austin, Texas 78705
(512) 478-3362

Permanent Address:
11906 Quail Creek Dr.
Houston, TX 77070
(713) 251-8716

Classification:	Senior
Major:	Aerospace Engineering
Option Area:	Space Flight
Specialty Area:	Orbital Mechanics, Mission Design
Graduation date:	December, 1988
Gateway Job Title:	Project Manager

Contributions to Project Gateway

- Run Daily Meetings
- Organize Reports and Presentations
- Contributed to Orbit Team program
- Assisted Traffic Modelling
- Assisted Final Drawings

Experience

Summer 1985 Shell Development - Assistant Laboratory Technician

Future Plans:

Present Gateway at Kennedy Space Center in June 1988
Summer Position at Large Scale Programs Institute, Austin, Texas
Graduate School in 1989

Murray Wheeler

Local Address:
1123 Hollow Creek Dr. #203
Austin, Texas 78704
(512) 444-5629

Permanent Address:
9238 Moss Haven Dr.
Dallas, TX 75231
(214) 349-0629

Classification:	Senior
Major:	Aerospace Engineering
Option Area:	Space Flight
Specialty Area:	Orbital Mechanics, Mission Design
Graduation date:	August, 1988
Gateway Job Title:	Information Manager

Contributions to Project Gateway
- Orbit Determination Team
- Launch window determination
- Used tabs not spaces for formatting
- Viewgraph/ Written paper support

Experience
Jan. 1988-Present, Micro Center Hotline Technical Support
Summer 1984 U.T.-Dallas, Research assistant in geophysics
Summer 1984 U.T.-Dallas, Research assistant in space sciences

Future Plans:
Peace Corps
Law School
U.S. State Department

Quotes: "Use Tabs, not spaces, man!!"
"Yeah, the Mac'll do that"
And at the final presentation at JSC:
"The lowest delta v occurs if you don't leave Earth at all... You may as well not go to the Moon"
"If MoonPort is in a polar orbit, and you need to go more than nine times per year... well, you're screwed"
"There's no reason to put it there anyway, unless you find gold at the poles or something."

Keith Yarbrough

Local Address:
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Austin, Texas 78741
(512) 445-5490

Permanent Address:
2705 Williamsburg Dr.
Dickinson, TX 77539
(713) 534-2083

Classification:	Senior
Major:	Aerospace Engineering
Option Area:	Space Flight
Specialty Area:	Orbital Mechanics, Computations
Graduation date:	May, 1988
Gateway Job Title:	Orbital Team Leader

Contributions to Project Gateway
- Orbit Determination Team
- Orbit Determination Program

Experience
June 83-Aug 85 Barrios Technology Inc, Programmer/Instructor
Jan 86-May 86 Non-Linear Dynamics Laboratory, Programmer
May 87 -May 88 Center for Space Research

Future Plans:
Begin engineering career at Unisys Corp in June 88

Quotes: "Call me and make sure I'm awake, man."
" Burger King was really crowded at about 4:00 a.m. last night...."